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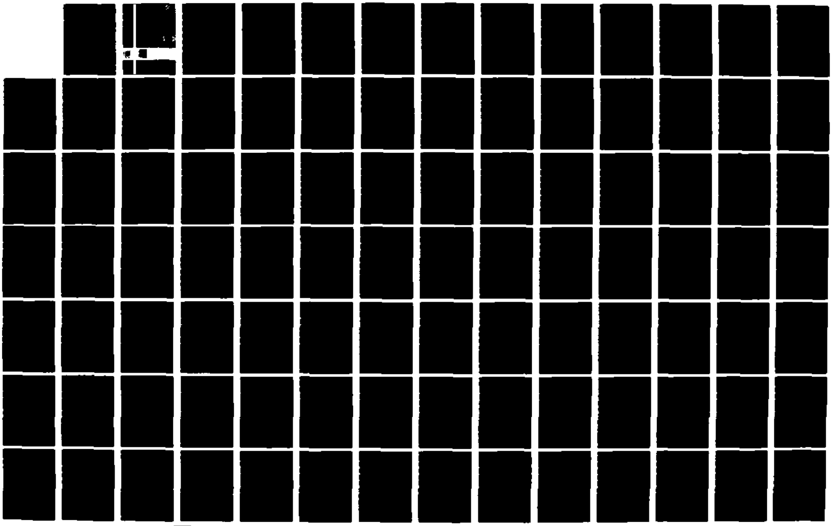

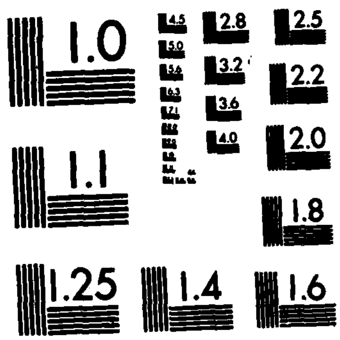

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Seventh Annual Summary Report

Contract No. N00014-75-C-0694
Contract Authority NR-097-395

CONVECTIVE HEAT TRANSFER FOR SHIP PROPULSION

Prepared for

Office of Naval Research
Code 431
Arlington, Virginia

Prepared by

J. S. Park, M. F. Taylor and D. M. McEligot

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Measurements of heat transfer parameters in pulsating and steady forced turbulent air flow through a vertical circular tube, which was resistively heated, are reported. Inlet Reynolds numbers varied from 19,000 to 102,000; Mach numbers were 0.15 or below; pulsation frequencies ranged from 2.1 to 3.6 Hz and the peak-to-peak pressure fluctuations varied from 9 to 29 percent of the mean pressure. At these conditions the non-dimensional frequency $\alpha = r\sqrt{2\pi f/\nu}$, varied from about 4 to 7 1/2; in laminar flow, quasi-steady approximations became weak when this frequency becomes greater than about two, but for turbulent heat transfer in this Reynolds number range the

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CONVECTIVE HEAT TRANSFER FOR SHIP PROPULSION

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Abstract

Measurements of heat transfer parameters in pulsating and steady, forced, turbulent air flow through a vertical circular tube, which was resistively heated, are reported. Inlet Reynolds numbers varied from 19,000 to 102,000; Mach numbers were 0.15 or below; pulsation frequencies ranged from 2.1 to 3.6 Hz and the peak-to-peak pressure fluctuations varied from 9 to 29 percent of the mean pressure. At these conditions the non-dimensional frequency $\alpha = r\sqrt{2\pi f/\nu}$, varied from about 4 to 7 1/2; in laminar flow, quasi-steady approximations became weak when this frequency becomes greater than about two, but for turbulent heat transfer in this Reynolds number range the limitations are still to be determined. Direct comparison between steady and pulsating runs at the same values of the control parameters essentially confirmed the quasi-steady analyses for $Re \gtrsim 5 \times 10^4$.

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NOMENCLATURE

Symbol	Definition
a_o	Speed of sound
c_p	Specific heat at constant pressure
D	Diameter of tube
f	Frequency, cycles/sec.
G	Average mass flux, $\rho\bar{V}$
Gr	Grashof number, $gD^4q''_w/(\nu^2kT)$
g	Gravitational acceleration
g_c	Dimensional conversion factor, e.g., 32.174 lbm·ft/(lbf·sec^2)
h	Heat transfer coefficient
k	Thermal conductivity
L	Length
M	Mach number
n	Exponent in heat transfer correlation
$\mathcal{O}$	Order of
p	Pressure
$\bar{p}$	Mean pressure
P	Period
Pr	Prandtl number, $\mu c_p/\rho$
q^+	Non-dimensional heat flux, $q''_w/(\rho\bar{V}c_pT_i)$
r	Radius of tube
Re	Reynolds number, $\rho VL/\mu$ (or, for tube, $4\overset{''}{m}/\pi D\mu$
Str	Strouhal number
T	Temperature
V	Bulk velocity

NOMENCLATURE--Continued

Symbol	Definition
$\bar{V}$	Mean bulk velocity
Y	Non-dimensional velocity amplitude

Subscripts

b	Bulk
i	Inlet
m	Mean
p	Pulsed
s	Steady
w	Wall

Greek symbols

α	Non-dimensional frequency, $r\sqrt{\omega/\nu}$
θ	Time
λ	Wave length
μ	Dynamic viscosity
ν	Kinematic viscosity, μ/ρ
ρ	Density
ω	Angular frequency, $2\pi f$

1. INTRODUCTION

Current Naval propulsion plants are powered by variations of the Rankine cycle (steam) or the open gas turbine cycle (air and combustion products) plus some diesel engines in small ships. Alternative power systems suggested include the closed gas turbine cycle and cycles involving dissociation of the working fluid in either a Rankine or a gas cycle. These latter two are believed to offer the potential of substantial improvement in the power-to-weight ratio of the propulsion plant.

Convective heat transfer provides the dominant thermal resistance in several components of conventional steam power plants as well as in all heat transfer components in gaseous cycles. In order to design propulsion plants with better power-to-weight ratios and/or fuel economy reliably, the convective heat transfer must be predicted accurately. The present studies consider basic problems in convective heat transfer and flow friction that are important in all of the above.

Pulsating internal gas flows occur frequently in practise. In some cases the pulsations are unintentional consequences of the flow equipment employed, e.g., reciprocating compressors, and in others they are meant to accomplish a purpose such as improving convective heat transfer [Lemlich, 1961]. In either case it is important for the designer to know the effects of the pulsations on the time-mean heat transfer parameters for his/her proposed range of operations. Also, the so-called mass

flowmeter, or thermal flowmeter, employs wall temperature measurement for convective heat transfer in a tube in order to deduce the mass flow rate of a gas [Zinsmeister and Dixon, 1966]; the extent to which its steady flow calibration is valid for non-steady flows also depends on the magnitude of the effects of pulsating flows.

The present study utilizes a vertical circular tube with flow pulsations superposed on the throughflow. The frequencies are sufficiently low that possible acoustical resonances are not expected to be important.

1.1. Governing parameters of non-steady flow

Smolderen [1977] provides a general introduction to the theory of unsteady fluid dynamic phenomena and identifies pertinent non-dimensional parameters. The Strouhal number

$$Str_L = \frac{L}{VP} = \frac{fL}{V}$$

is the ratio of the length of the flow path to the distance traveled by a typical fluid particle during the period of a cycle. It is also called the reduced frequency by some authors. If $Str_L << 1$, unsteady terms in the governing equations become negligible and the flow can be treated as quasi-steady. For acoustic disturbances, the ratio of the length of the flow path to the wave length of sound waves,

$$\frac{L}{\lambda} = \frac{L}{a_o P} = \frac{Lf}{a_o} = M \cdot Str_L$$

is an important parameter. If it is small, the flow is considered quasi-steady.

For consideration of viscous effects, one examines the ratio of the length to the penetration depth for vorticity diffusion, which is $O(\sqrt{\nu P})$ in viscous flows. The following equivalency results:

$$\frac{L^2}{P\nu} = \left[\frac{L}{\sqrt{P\nu}}\right]^2 = \left[L\sqrt{\frac{f}{\nu}}\right]^2 = Re_L \cdot Str_L$$

If this grouping is small, vorticity can diffuse through the entire field in a fraction of a period. For fully developed flow in a tube, the radius is the logical characteristic length, so $r\sqrt{f/\nu}$ is the appropriate parameter; many authors use the angular frequency, $\omega = 2\pi f$, and for this non-dimensional frequency as $\alpha = r\sqrt{\omega/\nu}$ [Baird et al., 1966].

For a thermal problem, thermal diffusion may become important and the appropriate length scale is the penetration depth of a thermal disturbance, $O(\sqrt{kP/\rho c_p})$. The related parameter becomes

$$\frac{L^2}{kP/\rho c_p} = \frac{\nu\rho c_p}{k}\frac{L^2}{\nu P} = Pr \cdot Re_L \cdot Str_L$$

or, for fully developed flow in a tube,

$$\frac{r^2}{kP/\rho c_p} = \frac{\nu\rho c_p}{k}\frac{r^2}{\nu P} = \frac{Pr}{2\pi} \cdot \alpha^2$$

If this parameter is small, the thermal disturbance penetrates the entire field and the thermal treatment can be quasi-steady provided the velocity field is also quasi-steady.

Richardson [1967] presents additional background and develops comparable non-dimensional parameters via a different approach. For turbulent flows, he suggests that an "a.c. boundary layer thickness," $\sqrt{\nu/\omega}$ (a vorticity penetration depth from Smolderen) be compared to the "laminar sublayer thickness," $y^+ \gtrsim 5$, giving $5\sqrt{\mu\omega/\tau_w}$ as a parameter and a criterion for interation with non-steady effects in turbulent flows.

1.2. Related work

Lemlich [1961], Richardson [1967], Barnett [1970] and others present reviews of previous studies of heat transfer to pulsating flows; the literature survey which accompanied the present work is included herein as Appendix A.

For fully developed, laminar flow in a tube Mullin and Greated [1980] point out that for low values of the viscous frequency parameter, $\alpha = r\sqrt{\omega/\nu}$, quasi-steady assumptions should hold, while at $\alpha \gtrsim 10$ the velocity profile changes substantially.

Lemlich [1961] shows that for fully developed flow with constant properties, if the heat transfer coefficient varies as V^n for steady flow, the quasi-steady prediction of "enhancement" would be

$$\frac{\bar{h}}{h_{ss}} = \frac{(2\pi)^{n-1}\int_0^{2\pi} V^n(\theta)\, d\theta}{\left(\int_0^{2\pi} V(\theta)\, d\theta\right)^n}$$

provided the flow does not reverse. He notes that the result is independent of frequency and, if $n < 1$, a decrease in $\bar{h}$ will be predicted.

Mueller [1957] calculated the enhancement for a rectangular wave representation of $V(\theta)$ and showed that the predicted reduction for

dimensionless amplitudes of 1 and less (i.e., non-reversing) would be small. For a symmetric wave $V(\theta)$ of dimensionless amplitude 0.5, the reduction would be about 2 to 3 percent. He also derived a criterion for quasi-steady turbulent flow by considering the "laminar" sublayer and presented it as a function of dimensionless amplitude and the reciprocal of α^2.

Baird et al. [1966] predict that for pulsations of the form

$$V = V_m (1 + \Upsilon \cos \omega\theta)$$

the enhancement would be

$$\frac{\bar{h}}{h_{ss}} = \frac{1}{2\pi} \int_0^{2\pi} (1 + \Upsilon \cos \omega\theta)^n \, d\theta$$

under the quasi-steady assumptions. This value is negative but yields only a small reduction for $\Upsilon \lesssim 1$. They extend the treatment to reversing flows and show that for $\Upsilon \gtrsim 1.5$ the heat transfer coefficient is predicted to improve substantially. For their conditions they estimate the limit of the quasi-steady approximation to be $\alpha \lesssim 7.4$, based on residence time considerations.

Barnett and Vachon [1970] solved the non-steady problem approximately for fully developed, turbulent pipe flow. The turbulent diffusivities were taken as stationary at the values corresponding to the mean flow. They predicted significant increases of heat transfer at low frequencies and large amplitudes; the calculated improvement also increases as the Prandtl number is reduced.

Thomas [1974] applied a surface renewal model and predicted only slight changes as the pulsation frequency increases in a water flow. He quotes Lu [1972] and Brown, Margolis and Shah [1969] as recommending $4\alpha^2 \gtrsim 0.1\ \overline{Re}_D$ as a limit for quasi-steady flow.

Measurements of heat transfer to pulsating air flow have emphasized high frequency conditions where acoustical resonances become important [Lemlich, 1961]. Of those which concern low frequency pulsations about half the experiments used steam-to-air heat exchangers which do not normally permit precise comparisons. Enhancements and reductions of the order of 10 to 80 percent have been reported [Havemann et al., 1956; Chalitbhan, 1959].

With electrical heating giving an approximately constant wall heat flux, Romie [1956] conducted studies at Re = 5000 and found reductions in heat transfer coefficients of up to 10 percent and enhancements up to about 20 percent. For a range 540 < Re < 11,000 in comparable apparatus, Mamayev, Nosov and Syromyatnikov [1976] found apparent enhancement for low frequencies and reductions at their highest frequency. Data at higher Reynolds numbers do not appear to be available with a constant wall heat flux as the boundary condition and with moderate or low pulsation frequencies.

In summary, the analyses generally predict only a slight modification of heat transfer parameters in pulsating turbulent flow whereas experiments have found larger effects. Therefore, it is important to measure the heat transfer parameters in typical flows where data are not available in order to test the analytical predictions for normal operating conditions.

1.3. Objective

The purpose of the present study is to determine by measurement whether the predictions of quasi-steady analyses - e.g., no significant modification of heat transfer parameters - are reasonable for pulsed turbulent flow at typical Reynolds numbers and moderate frequencies and amplitudes. In order to avoid some uncertainties of previous studies, a direct comparison method is employed.

2. EXPERIMENT

2.1. Apparatus

Data were obtained with upflow through a vertical circular tube heated resistively. The apparatus and procedures were similar to those used by Pickett, Taylor and McEligot [1979].

Measurements were obtained with the open loop apparatus shown schematically in Figure 1. A regulated gas supply flowed directly into the system or through a single-acting "Gas Booster Pump" from Haskell Manufacturing Company. The first source was used for steady flow and the second provided pulsations superposed on a main flow. From the pump the gas flowed through 3.2 meters of 9.5mm diameter tubing to a heat exchanger of 14mm ID and 1.9m long. The flow continued through the same diameter tube 0.67m to a fitting containing a thermocouple used to measure the gas temperature and another fitting in which a Model SCD 147 pressure transducer from Data Instruments, Inc. was located to measure pressure fluctuations. The flow continued through the same diameter tubing for another 7.6cm and at

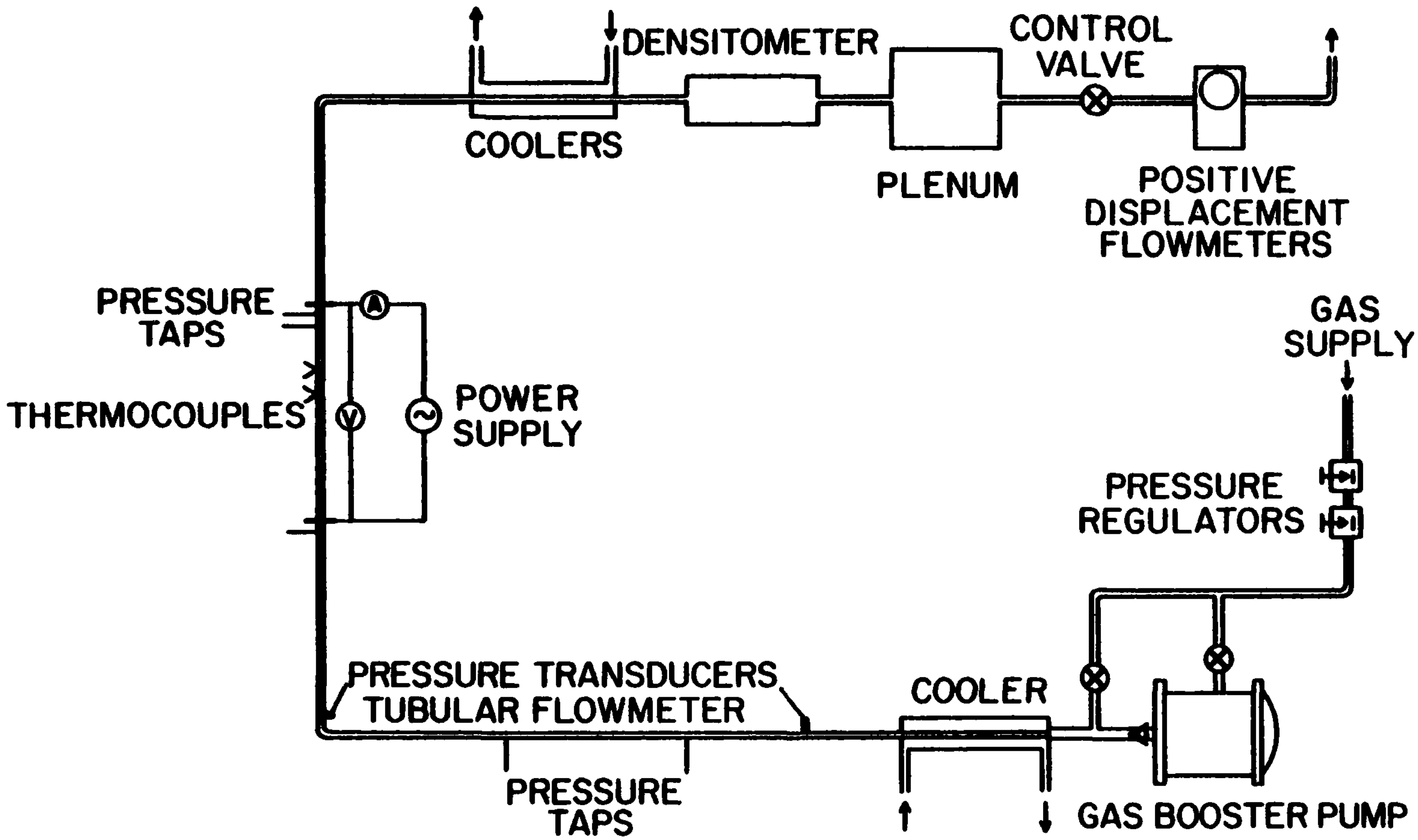

Figure 1. Schematic diagram of experimental apparatus.

that point the flow entered a tube 1.54m long with a 5.87mm diameter; this tube served as an alternate flowmeter for steady flow runs. At the exit of this tubular flowmeter was an elbow which served as the entrance to the test section.

The test section was a tube of Inconel 600 with inside diameter of 5.87mm and wall thickness of 0.292 mm. It consisted of a heated section of 60 diameters in length preceded by an unheated section of 60 diameters and followed by an unheated section of 56 diameters. A Kulite model XT-140-100G subminiature pressure transducer was mounted flush with the inside of the tube immediately beyond the elbow at the entry of the test section.

The remainder of the gas flow path consisted of approximately 2.1m of tubing with the same diameter as the test section followed by 1.4m of 9.5mm ID tubing joined to the heat exchanger tubing which had an ID of 14mm and was 1.9m in length. A 1.3m length of the same diameter tubing continued on to a densitometer which had an inside diameter of 8.3cm and was 61cm long. A 0.7m length of the 14mm ID tubing continued from the densitometer to a plenum chamber of 0.14m ID and 0.24m length. From the plenum a line of the same diameter as the entry and 5.2m long ran to the positive displacement meters where the air was exhausted to the atmosphere. A flow control valve was located 0.3 meters after the plenum chamber.

In low temperature runs, electrical resistance heating of the test section yielded an axial heat flux distribution which exponentially approached a constant value within two diameters and then remained

constant within a few percent until near the end of the section. Tube wall temperatures were obtained from premium grade Chromel-Alumel thermocouples, 0.13mm (0.005 in.) diameter, which were spot welded to the outside of the tube. Three pressure taps, with holes of about 0.30mm diameter, were used. One was located five diameters below the lower electrode and the other two were about four and nine diameters below the upper electrode.

The static pressure at the test section inlet was measured with a Heise gauge and the Kulite pressure transducer. Pressure drop was measured in steady flow with an MKS Baratron Model 77 differential pressure meter. Pressure fluctuations at the beginning of the unheated entrance section were measured with the Kulite transducer. The signals from both transducers were recorded on a Hewlett-Packard x-y recorder. Volume flow rates were measured with several Parkinson-Cowan positive displacement flow meters in parallel. The test section was completely enclosed by a heat shield to restrict convective air currents and to help stabilize the heat loss from the tube to the environment.

2.2. Procedure

To examine the differences in heat transfer parameters between steady flow and pulsating flow, an experimental procedure was evolved to keep all control conditions as close to constant as possible during comparison runs.

The quantities controlled were the volume flow rate which determines the mass flow rate and Reynolds number, the electrical current which determines the heating rate, and the inlet pressure level. As a

consequence, the gas, Reynolds number, Mach number and non-dimensional heating rate were held fixed while only the pulsating parameters, such as α, Str, etc., changed from zero to a chosen value. Instruments were not changed during a set of runs at the same conditions, thereby reducing the pertinent experimental uncertainties to relative (or comparative) values rather than absolute values.

Normally the pulsed run was conducted first at the nominal flow rate, pressure and heating rate desired. After the data were recorded the pulsed gas supply was stopped and the control settings were adjusted to give the same instrument readings in steady flow. Electrical current and pressure could be controlled closely but, since the flow rate is deduced from measurements over a time interval with the positive displacement flowmeters, setting the flow was an iterative procedure. The steady flow rate would be set as close as practical to the previous pulsating flow rate, then after the data were recorded it would be set to a slightly different value for a second steady run. The latter flow rate was chosen so that the steady flow data could be corrected to the conditions of the pulsating run by interpolation if necessary. Normally the differences in mass flow rate were less than two percent so changes were minimal.

The reproducibility of the measurement technique was checked in two ways. Air data in steady flow had been obtained previously in two other test sections by Serksnis, Taylor and McEligot [1978] and Pickett, Taylor and McEligot [1979]. It was found that each had a series of runs at Re_i near 80,000 and various heating rates so these were compared

to present measurements at the same conditions. For the three sets of data which spanned a five year period, it was found that in the downstream region the normalized Nusselt number, $Nu/(0.021Re^{0.8}\ Pr^{0.4})$, agreed to within three percent at low heating rates ($T_w/T_b \approx 1.2$) and within two percent at higher heating rates ($1.4 < T_w/T_b < 1.8$).

Secondly, the reproducibility of the present measurements was tested at the end of the experiments by duplicating one of the first runs with $Re_i \approx 60{,}000$, $q^+ = 0.0014$ (maximum $T_w/T_b \approx 1.5$) and steady conditions. The mass flow rate could be reproduced to better than 0.2%, the test section inlet pressure to within less than 0.1% and the electrical current within the accuracy of ammeter ($\approx$ 0.25%). The resulting values of $(T_w - T_{b,in})_{max}$ differed by 2.1%, leading to agreement of the fully developed Nusselt numbers within less than 3% again.

2.3. Range of variables

Thirteen sets of runs were conducted with air ($Pr \approx 0.7$). A nominal Reynolds number of about 60,000 was chosen as a reference but the range covered was $19{,}000 < Re < 102{,}000$. Most data were taken with moderate heating ($q^+ \approx 0.0015$) with a few runs with q^+ up to 0.0034 (maximum $T_w/T_b \approx 2.3$) to investigate effects of property variation. The maximum Mach number was 0.15 and the quotient Gr_i/Re_i^2 was less than 0.012 so compressibility and buoyancy effects were believed to be negligible. The operating range of the pulsating "Gas Booster" pump was 2.1 to 3.6 Hz.

The response time of the test section, due to its thermal capacity, was about one second or longer at the conditions of the experiments.

Thus, the wall temperature fluctuations were damped by the test section acting as a filter. Since the response time was not considerably larger than the period of the forced pulsations, the wall temperature oscillated slightly. The amplitude was usually about $\pm$ 3/4°C. with a few cases approaching $\pm$ 1 1/2°C. For the nominal case at Re $\approx$ 60,000, the latter amplitude is less than one percent of the temperature difference $T_w - T_i$ downstream. In data reduction the mean wall temperature was taken as the mean of the two extremes observed during the pulsations.

For the pulsating runs, Str_L was less than 0.1 for all cases and, correspondingly, Str_D was 0.0016 or less. Both were low enough to expect quasi-steady conditions relative to residence times. The total flow length from the pulsed flow source to the exit was about 20m or approximately 1/7th of the wavelength of sound at these frequencies, so the liklihood of significant acoustical resonances is believed to have been negligible. The non-dimensional frequency or Stokes parameter, $\alpha = r\sqrt{2\pi f/\nu}$, ranged from 4.1 to 7.6 and its thermal counterpart $r\sqrt{2\pi f\rho c/k}$ was slightly less; if the flow were laminar, these magnitudes would invalidate quasi-steady idealizations [Greated and Mullin, 1980]. The measured magnitude of the pressure pulsations, $\Delta p/\bar{p} = 2(p_{max} - p_{min})/(p_{max} + p_{min})$, ranged from 0.09 to 0.29 with the magnitude of the bulk velocity pulsations being estimated as approximately half these values.* Thus, the amplitudes of the pulsations could be considered small to moderate with none approaching flow reversal.

The heat transfer data are tabulated in Appendix B.

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*The small size of the test section precluded direct measurement of $\Delta V/\bar{V}$. The idea that $\Delta V/\bar{V} \approx \frac{1}{2}\, \Delta p/\bar{p}$ is based on an incompressible flow

3. RESULTS

3.1. Pulsation wave shape, $p(\theta)$

The commercial gas booster pump does not yield a pressure fluctuation that could be described as a pure sine wave, but typically it could be considered sinusoidal as a first approximation. Figure 2a shows measurements of the usual wave form in these experiments and Figure 2b shows the most different wave form observed. The latter occurred at the slowest frequency used, 2.1 Hz. Close examination of the usual wave form shows an almost linear rise in pressure followed by an exponential decay, but normally this decay was interrupted by the next pressure stroke before it approached a steady pressure. The fraction of time during which the pressure was rising was 30 to 40 percent in most cases. Usually, the decay fraction increased as the Reynolds number decreased.

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approximation relating $\Delta p/\rho \approx KV^2$ where K is an overall loss coefficient. Prof. Edw. J. Kerschen [AME, Univ. Arizona, 1981] has suggested an alternate approach, considering the system as a long, frictionless tube (non-steady) ended with a restriction, the control valve (quasi-steady). His one-dimensional perturbation solution yields the spatial dependence of the velocity pulsation u' in the pipe as

$$\frac{u'}{A} = \left\{\frac{i \sin [k(x - L)/\beta^2] + Dk/\beta^2 \cos[k(x - L)/\beta^2]}{-i \sin [kL/\beta^2] + Dk/\beta^2 \cos[kL/\beta^2]}\right\} e^{-ikMx/\beta^2}$$

where $k = \omega/a_o$, A is the amplitude of the imposed pulsation, $\beta = \sqrt{1 - M^2}$ and D is a function involving the contraction ratio at the restrictor. He also outlined another technique in terms of a velocity potential in order to obtain both the velocity and pressure pulsations.

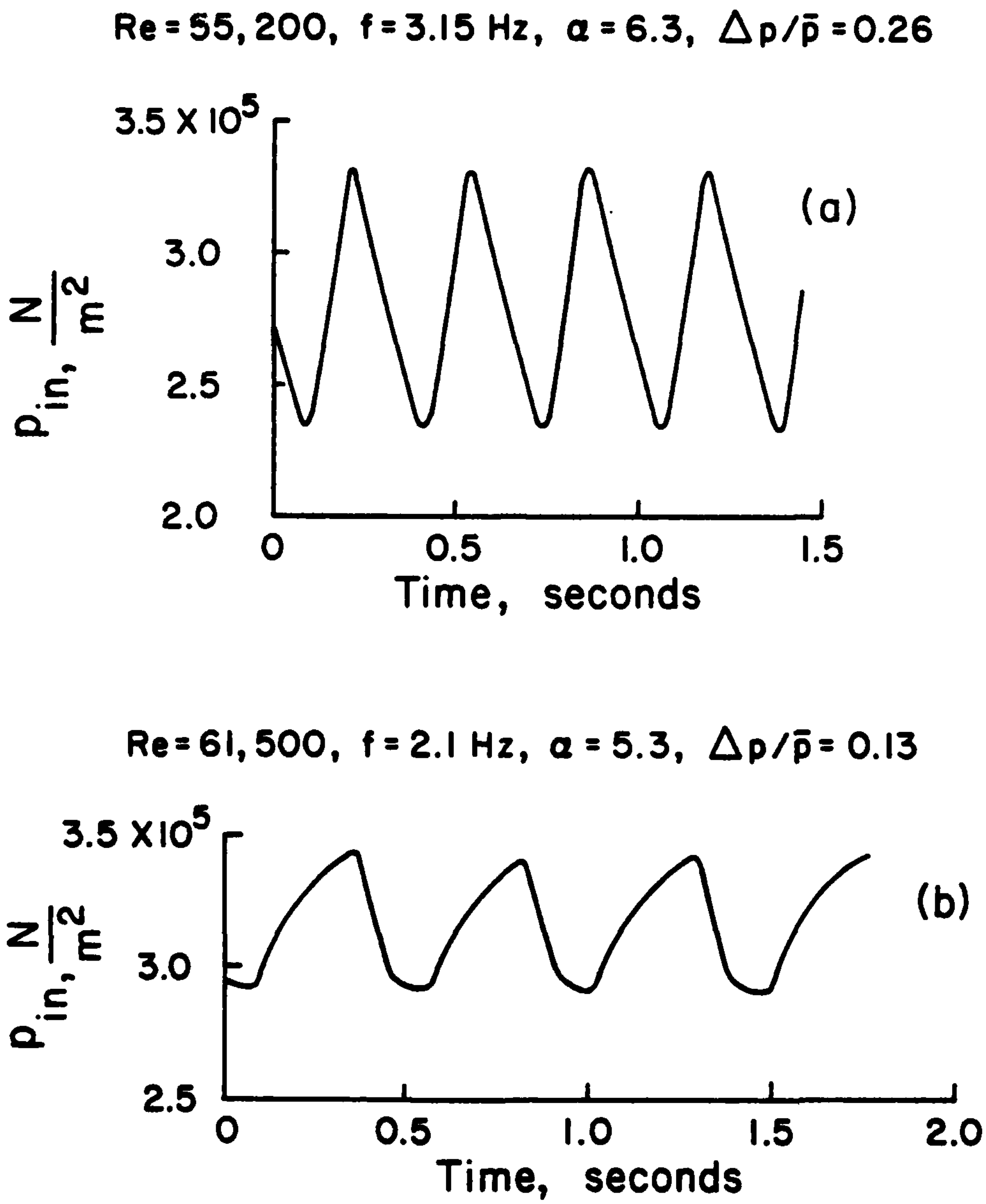

Figure 2. Typical wave forms of pulsating pressure.

One can apply the quasi-steady predictions of Mueller [1957] for rectangular waves to estimate the effect of asymmetry in the wave form. With symmetrical shapes at a non-dimensional velocity amplitude of 0.2, the reduction in heat transfer coefficient is predicted to be about one-half percent. With $V/\bar{V} = 0.2$ for the rise and $V/\bar{V} = 0.4$ for the decrease, the reduction is only one percent so the sensitivity to shape or asymmetry is not expected to be significant at moderate amplitudes.

By comparing the signals measured by the two pressure transducers, it was possible to estimate the importance of the location of the test section transducer. The distance between the two transducers was approximately twice the test section length and it included flow through an elbow and a couple additional fittings, so the change in $p(\theta)$ would be expected to be greater than along the test section. For a given run there was no evident change in the shape of the pressure fluctuation. The decrease in the non-dimensional amplitude was approximately 10 percent for $\Delta p/\bar{p} \approx 0.3$ and for $\Delta p/\bar{p} \approx 0.1$ it was up to 40 percent. Therefore, the change in $\Delta p/\bar{p}$ along the test section would be estimated to be less than 20 percent and the change in $\Delta V/\bar{V}$ would be expected to be less than 10 percent. Accordingly, the data are reported with the transducer at the test section inlet providing $\Delta p/\bar{p}$ for reference.

3.2. Typical thermal entry behavior

Air measurements at $Re_i \approx 5.5 \times 10^4$ and a moderate heating rate are presented to illustrate typical results for the nominal case. The pulsation wave form, $p(\theta)$, has been presented in the previous

section; at a forcing frequency of 3.15 Hz, α was 6.3 and $\Delta p/\bar{p}$ was 0.26, one of the higher amplitudes obtained. In the figures, circles represent data with pulsating flow.

The wall temperature measurements are seen in Figure 3 to yield the axial profile usually expected for steady flow with a constant wall heating rate. For the comparable steady flow data, the flow rate was reproduced to within 1 1/2 percent and the electrical current to within 0.3 percent. The quasi-steady theory predicts only slight differences and it is evident from even the raw data that there are not large differences at these conditions. In the thermal entry most pulsed data fall between the two steady runs as would be expected from the Reynolds numbers if there were no effect. Further downstream the pulsed data appear slightly lower than the mean of the steady data.

In order to eliminate the axial variation in bulk temperature from the comparison, the local Nusselt numbers are shown in Figure 4. The differences are too small to discern so it is concluded that for these conditions there is no significant effect even though α is well above two, the approximate quasi-steady limit in laminar flow.

The slight difference in Reynolds number may be treated by comparing values of $Nu/Re^{0.8}$. Normalizing then allows a closer comparison as in Figure 5. For this set of data the average difference is about 1/2 to 1 percent with a scatter of the same magnitude. Most of the data for the pulsed run are below those for the smooth run, in agreement

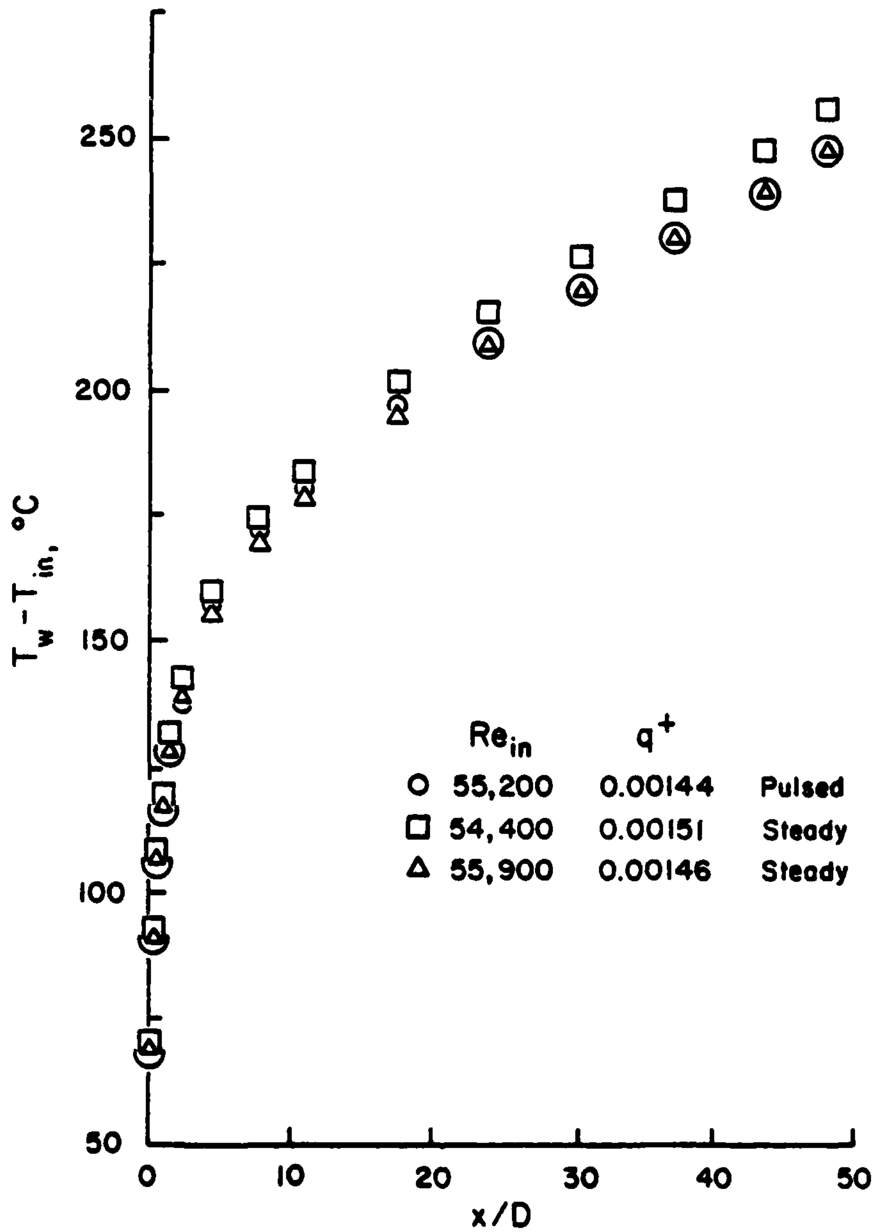

Figure 3. Comparison of pulsed and steady measurements at nominal conditions. Wall temperatures.

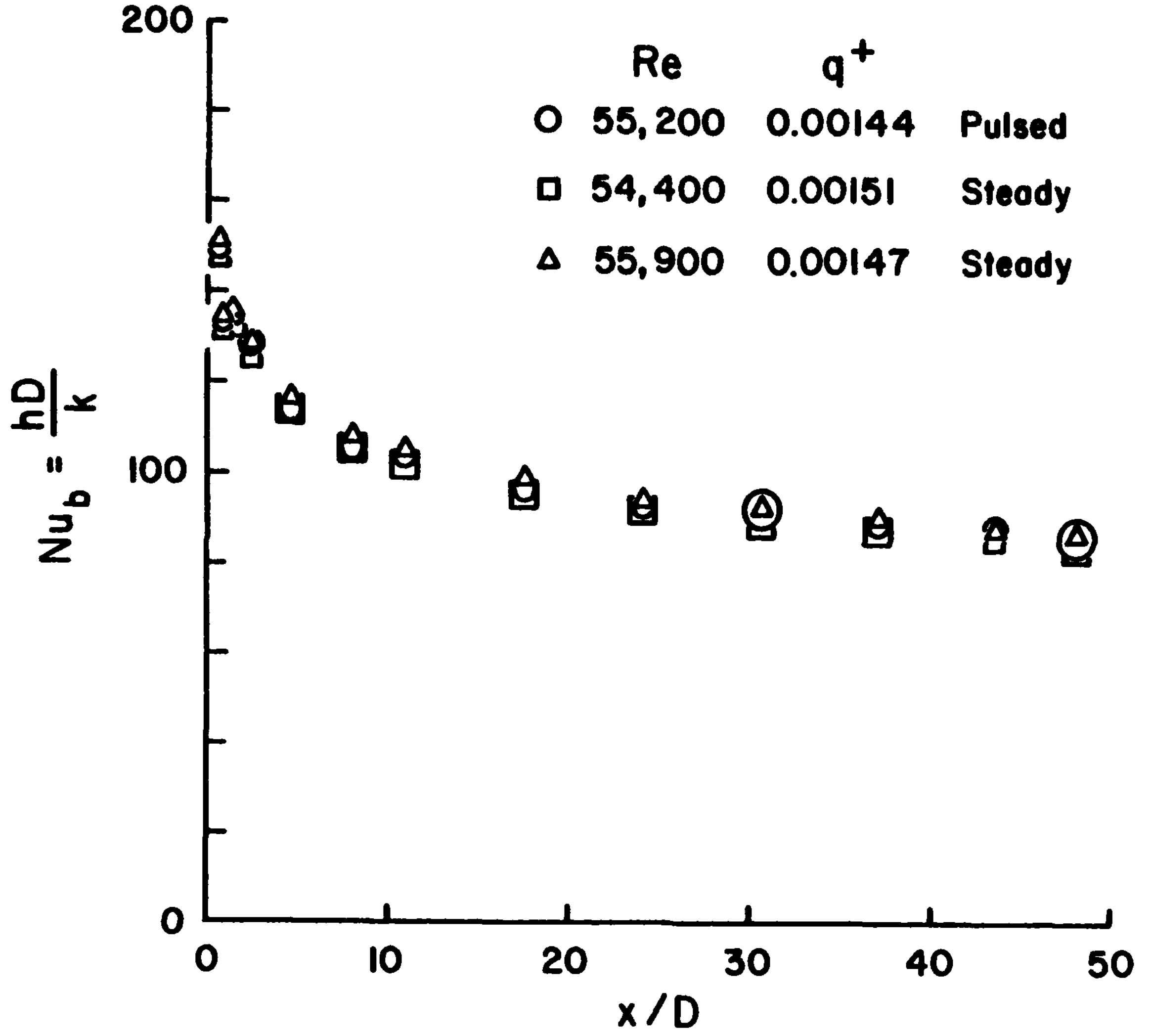

Figure 4. Comparison of heat transfer parameters in pulsed and steady flow at nominal conditions.

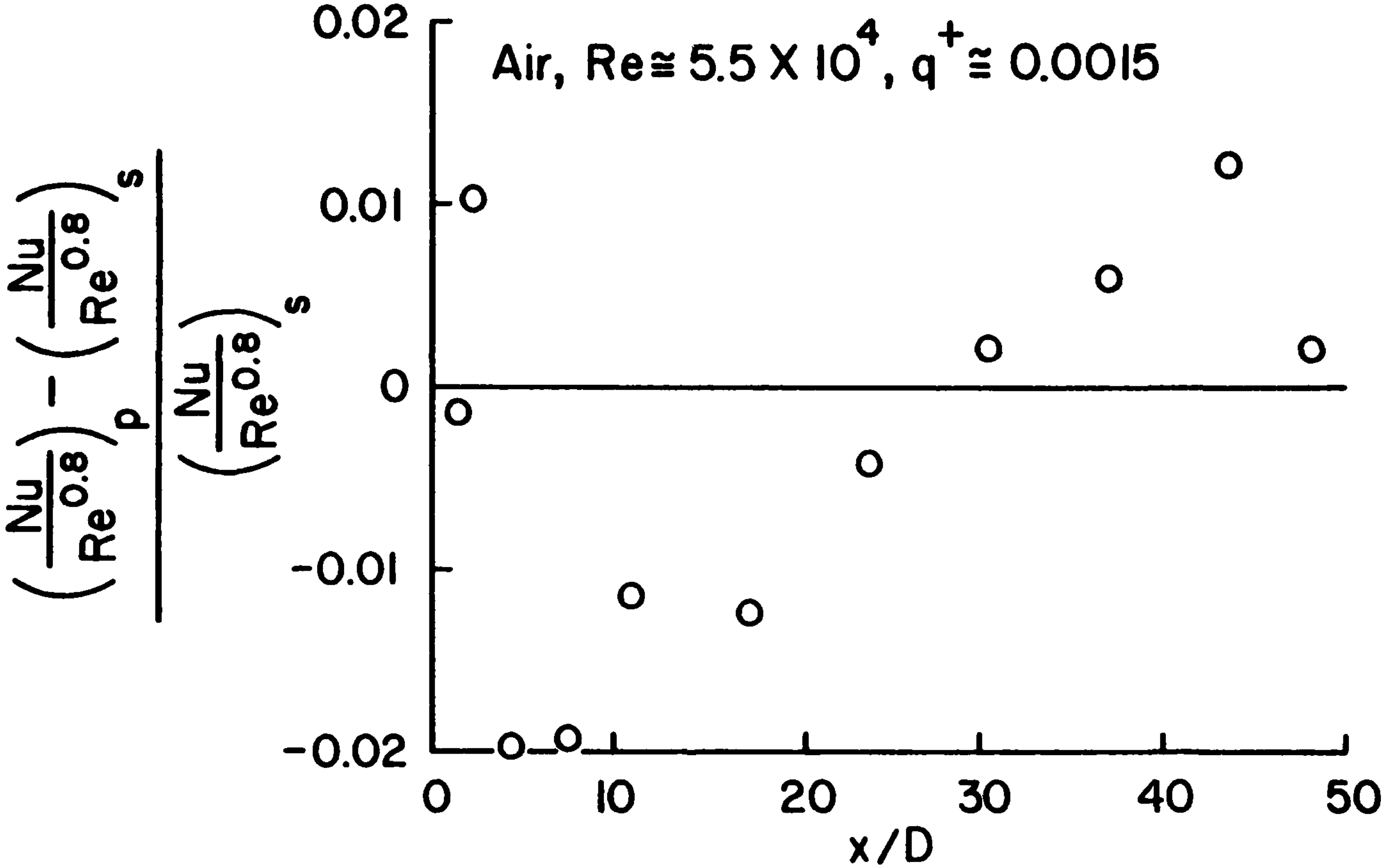

Figure 5. Normalized comparison of heat transfer parameters.

with the quasi-steady predictions of Mueller [1957] and Baird et al. [1966]; the order of magnitude of the reduction is the same as predicted. (More exact comparison is not warranted due to the attainable level of reproducibility mentioned earlier.) This quantity,

$$\frac{\left(Nu/Re^{0.8}\right)_p - \left(Nu/Re^{0.8}\right)_s}{\left(Nu/Re^{0.8}\right)_s}$$

will be used in the rest of this paper for comparison of the pulsed and steady measurements.

3.3. Variation of parameters

The direct comparisons for all thirteen sets of runs yielded maximum differences for individual sets ranging from 0.7 to 7.6 percent. In most cases the parameter $Nu/Re^{0.8}$ was less for pulsating flow than for steady flow. The effects found were less than reported earlier [Havemann et al., 1956; Romie, 1956; Chalitbhan, 1959] and were closer to the predictions of the quasi-steady analyses (which indicate only slight effects at moderate amplitudes).

The data were examined for trends as the control parameters were changed. No consistent variation was found relative to non-dimensional amplitude; the largest effects were found at low amplitudes rather than at high values as predicted by quasi-steady analyses. Three sets of data taken at higher heating rates, to see whether property variation was important, showed no common trend.

The variation with non-dimensional frequency α is plotted with inlet Reynolds number as a parameter in Figure 6. Also shown on the

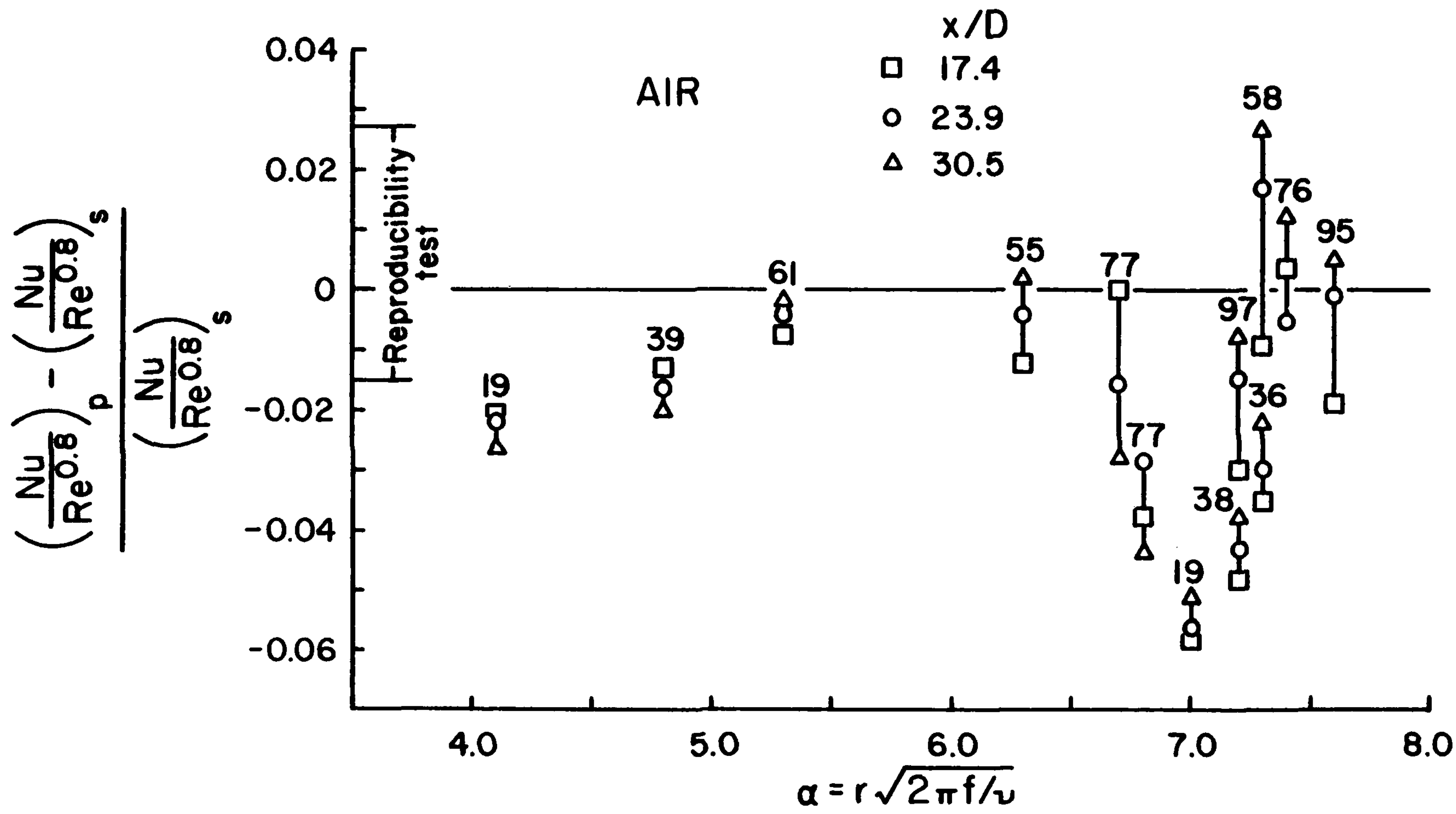

Figure 6. Comparison of pulsed and steady measurements.
(Number shown above each set of symbols is Re x 10^{-3})

left is the range of reproducibility mentioned earlier for the steady runs; this range provides a measure whether differences should be considered significant. The symbols identify the differences calculated at three axial locations from the thermal entry to downstream.

Most of the data fall within the range of scatter found in the reproducibility runs. For the nominal case of Re $\approx 6 \times 10^4$ as well as 8×10^4 and 10^5, no evident trend is seen as α varies from 5 to 7 1/2. Thus, the present data for high Reynolds numbers agree with steady results or quasi-steady predictions.

The two points at $Re_i \approx 1.9 \times 10^4$ do show an increasing discrepancy as α is increased as do the few points at $Re_i \approx 4 \times 10^4$. These discrepancies are greater than the experimental uncertainty in the direct comparisons. At a given non-dimensional frequency the data for the lower Reynolds number are lower. By extrapolating these trends towards low α, one might interpret these data as implying that the limit of quasi-steady flow may be given by a threshold value of α which varies with the Reynolds number. For example, from the figure one might estimate a threshold α of about 2 - 3 for $Re_i \approx 1.9 \times 10^4$ and 4 - 5 for $Re_i \approx 4 \times 10^4$.

3.4. Discussion

For Re $< 4 \times 10^4$ at $\alpha \approx 5 - 7$ the present results showed reductions in heat transfer parameters greater than the one percent predicted by the quasi-steady analyses even taking the steady flow reproducibility into consideration.

The greater reduction of the Nusselt number observed at lower Reynolds numbers and $\alpha \gtrsim 7$ can be considered in relation to other criteria suggested for turbulent flow. Since convective heat transfer is dominated by the thermal resistance of the viscous layer ($y^+ \lesssim 30$), criteria relating to its thickness and turbulent bursting phenomena would seem appropriate. Richardson [1967] and Shemer [1981] suggest that when the "a.c. boundary layer thickness" becomes comparable to the "laminar" (linear) sublayer thickness y_ℓ, the velocity profiles will be altered. Their criterion can be rewritten as $\sqrt{4\pi Str_D/(Re_D^2 c_f)} \gtrsim 0.2$, an equality which is approached as the Reynolds number is lowered for a given tube and frequency, but it is obvious that if $\sqrt{\nu/\omega} >> r$ (i.e., $Str_D << 1$) then $\sqrt{\nu/\omega} >> y_\ell$ also.

Ramaprian and Tu [1980] suggest that the turbulent transport will be modified when the pulsating frequency is the same order as the turbulent bursting frequency, f_b. Using a correlation based on outer variables, $V/f_b D \approx 5$, by Rao, Narasimha and Badri Narayanan [1971], they develop the relation $Str_D \gtrsim 0.2$ as a test for significant effects. Chambers, Murphy and McEligot [1982] and others have found that the bursting frequency scales better with wall variables than outer variables; if their correlation is applied, the criterion would take the form $180\ Str_D/(\pi c_f Re_D) \gtrsim 1$. Both these bursting parameters increase as the Reynolds number decreases for a given frequency and tube. Each of the above criteria suggest a modification of heat transfer parameters as the Reynolds number is reduced in pulsating flow. However, at $Re \approx 1.9 \times 10^4$ in the present test section, the predicted turbulent

bursting frequency is still much greater than the forcing frequency of the pulsations.

Barnett and Vachon [1970] completed their analysis with the conclusion that the large changes in heat transfer noted in some experimental studies must be due to a change in the basic turbulent exchange mechanisms. Alternate explanations are experimental uncertainties and systematic error; measurements of heat transfer in internal flow typically become more difficult as the Reynolds number is reduced. It is known that it is difficult to measure the flow rate accurately in pulsating flows [Oppenheim and Chilton, 1955] particularly when a non-linear relation is involved (this difficulty was avoided in the present study by the use of the positive displacement flow meters).

The present test section is too small to permit direct measurement of the turbulence structure as by Shemer [1981] so resolution of the behavior in the range $10^4 < Re_D < 4 \times 10^4$ is deferred as a topic for later study. For the present we conclude that, relative to the quasi-steady predictions in the low Reynolds number range, there is possibly a small reduction which increases as α increases and as Re decreases.

The data for $Re > 5 \times 10^4$ essentially confirm the predictions of the quasi-steady analyses - that there is no significant difference from steady flow results - for α up to about 7 1/2 and $\Delta p/\bar{p} \gtrsim 0.3$ within the experimental uncertainty. As noted by Richardson [1967], Shemer

[1981] and others, for turbulent flow the penetration depth $\sqrt{\nu/\omega}$ should probably be evaluated using an effective viscosity considerably greater than μ in the turbulent core. Then the effective value of $\alpha_{eff} = r \sqrt{\omega/\nu_{eff}}$ would be reduced compared to laminar flow at the same frequency and tube diameter. This reduction in α would be expected to become greater as the Reynolds number increases. Thus, these data imply that $\alpha = 7$ at $Re > 5 \times 10^4$ corresponds to $\alpha_{eff} \lesssim 2$ (which would be the limit for quasi-steady behavior in laminar flow).

4. CONCLUSIONS

Heat transfer measurements in pulsating, turbulent flow of air were compared directly to results at the same values of the control parameters over the following ranges: $4.1 \lesssim \alpha < 7.6$, $q^+ \lesssim 0.0034$ and $19{,}000 \lesssim Re \lesssim 102{,}000$. All pulsating data agreed with the corresponding values for steady flow within 7 1/2 percent.

For $Re \gtrsim 5 \times 10^4$ the pulsating measurements essentially confirmed quasi-steady analyses, which predict a slight reduction in heat transfer parameters, within the reproducibility of the experiment. At lower Reynolds numbers the reduction was larger and increased as α was increased.

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Appendix A: LITERATURE SURVEY

J. S. Park*

Various studies over the past 30 years have been directed at the question of whether pulsating flow can produce increases in heat transfer. This interest is frequently motivated by the several practical situations of engineering applications, for example, in unstable systems of rocket motors, gas turbines, and heat exchangers with reciprocating devices or with compressors.

A survey of the available literature for heat transfer to pulsating turbulent flow is summarized in Table A-1 and Fig. A-1. Generally investigations on heat transfer to fluids in pulsating flow have shown increased rates of heat transfer but apparently conflicting data have been reported. In addition, many investigations have been limited in the range of variables determining the heat transfer phenomena and have used different pulse generation mechanisms, flow regimes, etc.

In the turbulent flow region, for example, references [2,4,5,8,9,15,17,18] show increases in heat transfer due to imparting pulsations to the fluid, while [1,10,11] report that these pulsations have no such effect. In [3,6,7,12,13,16,19-25] an increase in heat transfer was found in some cases and a reduction in others, depending on the frequency, amplitude and the Reynolds number.

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Nomenclature for Literature Survey

Symbol	Definition
a_o	Speed of sound
C_p	Specific heat at constant pressure
d_i	Pipe inside diameter
f	Pulsed frequency, cycles/sec
Gr	Grashof number based on wall heat flux, $gd^4 q_w''/(\nu^2 kT)$
h	Heat transfer coefficient
H	Heat transfer parameter, $Nu/Re^{0.8}$
k	Thermal conductivity
L	Length
M	Mach number
Nu	Nusselt number, hd_i/k
NR	Non-dimensional parameter for comparisons, $\lvert (Nu/Re^{0.8})_p - (Nu/Re^{0.8})_s \rvert / (Nu/Re^{0.8})_s$
n	Exponent on heat transfer correlation
$\bar{p}$	Time mean pressure
$\hat{p}$	Peak to peak amplitude of pulsating pressure
p	Pressure
q^+	Non-dimensional heat flux, $\dot{q}_w''/(\rho \bar{V} C_p T)_{in}$
Re	Reynolds number, $\rho V d_i/\mu$
r	Tube radius
Str	Strouhal number, $2\pi f d_i/\bar{V}$
t	Time
T	Temperature
$\bar{V}$	Time mean bulk velocity

Nomenclature for Literature Survey--Continued

Symbol	Definition
$\hat{V}$	Peak to peak amplitude of pulsating velocity
$\bar{V}$	Velocity
Y	Non-dimensional velocity amplitude, $\hat{V}/\bar{V}$

Subscripts

b	Bulk
in	Inlet
m	Mean
p	Pulsed
s	Steady state
w	Wall
x	Axial coordinate

Greek symbols

α	Non-dimensional frequency, $r\sqrt{2\pi f/\nu}$
λ	Wave length
μ	Dynamic viscosity
ν	Kinematic viscosity
ω	Angular frequency, $2\pi f$

Because the data reported in the above references were obtained with different parameters--such as Reynolds number, frequency, amplitude of pulsation, Prandtl number, waveform, etc. --the apparent conflict of the results is not surprising. However, the theory of the effects of turbulent pulsed flow on heat transfer is not, at present, well known or understood.

Hence, this paper represents a contribution toward a proper understanding of the pertinent variables for such a theory with experimental results in the ranges of turbulent flow and low frequency.

In the present Appendix, a review on the effects of unsteady turbulent flow generated by flow pulsation and sound fields on the rate of heat transfer is presented. The different studies are reviewed after classifying them as follows:

I. Measurements of heat transfer to pulsating turbulent flow.

   A) Water in steam-water heat exchangers (tube)

   B) Air with electrical heating (flat plate)

   C) Air in the low frequency range ($f \lesssim 40Hz$) with steam or electrical heating (tube)

   D) Air in the high frequency range ($f \lesssim 40Hz$) with steam or electrical heating (tube)

II. Theoretical studies and quasi-steady conditions for pulsating, turbulent flow.

Extensive reviews and bibliographies of the literature about pulsating flows in general are also presented in references [22], [27] and [28].

I. Measurements of Heat Transfer to Pulsating, Turbulent Flow

I.A. Pulsating Water Flow in Steam-water Heat Exchangers

References [1]-[7] have investigated the effect of pulsations in water flow on the overall heat transfer coefficient of a steam-water heat exchanger. Their works covered the Reynolds number range 1,500-8,500 with pulsation frequency covering the range 0.22-16.7 Hz. The primary purpose of these investigations was the study of improving the overall heat transfer coefficient by imparting pulsating motion to the flow in the heat exchanger. However, experimental data pertaining to this problem are clearly insufficient since they give conflicting conclusions.

Among those investigations, Karamercan and Gainer [6] and Herndon et al. [7] investigated broader ranges of the operating variables than others. Karamercan and Gainer [6] observed increases in the overall heat transfer coefficient of 0-700% for a Reynolds number of 1500-47,400 with 0 to 5.0 pulses/sec. They also showed the highest enhancements in the heat transfer coefficient obtained within a Reynolds number range of 7500 to 9500. Herndon et al. [7], employing 0.83 to 16.7 pulses/sec and a Reynolds number of 6,600 to 28,000, found some decreases at certain frequencies and increases at most frequencies for an exit pressure of 1 atm. In addition, the average enhancements observed at higher exit pressures (about 20-ft. head of water) were less than 1.0 for most of the frequency range studied.

In general, these investigations of heat transfer to pulsatile water flow in heat exchangers indicate possible causes of enhancement as follows:

1) to increase the level of turbulence in the pulsed stream

2) to cavitate the fluid next to the tube wall

3) to produce periodic reversals in the pressure gradient.

Karamercan and Gainer [6] state that periodic reversals in the direction of flow seemed to be the important parameter in the enhancement of heat transfer in pulsating flow because flow reversal increases cavitation and also promote a higher level of turbulence in the fluid. However, the manner in which these mechanisms improve the convective heat transfer coefficient is still somewhat vague.

I.B. Pulsating Air Flow Over a Flat Plate

References [8]-[11] are concerned with turbulent heat transfer from flat plates immersed in oscillating flows with frequencies from 3.0 to 680 Hz and Reynolds numbers from 10,000 to 48,000 as shown in Table A-1. Investigations by [8] and [9] resulted in increases in Nusselt number of 50 or 65%. In contrast Failer [10] and Miller [11] found practically no difference in heat transfer rates obtained with and without pulsations in the frequency range 3.0-200 cps. Unfortunately, those investigations are limited to a range of Reynolds numbers from 10,000 to 48,000, approaching the transition region in such flows.

Table A-1. Summary of data on heat transfer to pulsating turbulent flow.

a) Pulsating water flow in tube in steam-water heat exchanger.

Authors Ref.	Year	Fluid	Heating	Geometry	Re $\times 10^{-3}$	f, Hz	$\hat{V}/\bar{V}$ or $\hat{p}/\bar{p}$	T_w/T_b	p, psia	Test section d inch	Test section L inch	Pulsator	Results/notes
Martinelli, et al. 1	1943				2.66–77.3	.22–4.42				0.422	53.	reciprocating pump	h_p/h_s: >1. (laminar); ≈1. (turbulent)
West & Taylor 2	1952				30.–85.	1.7	—			2.067	216.	reciprocating pump	h_p/h_s = 0.95–1.7
Lemlich 3	1961				2. –20.	1.5	—			0.5	36.	interrupter valve	h_p/h_s: =1.1–1.8 (; <1.0 (downstream pulsator)
Baird, et al. 4	1966	Water	Steam	Tube	4.3–16.2	.8–1.7				3/4		air pulser	h_p/h_s =1.0–1.41
Keil & Baird 5	1971				24.0–26.0	.4–1.1			p <10 psig	0.527	37.	air pulser	h_p/h_s =1.0–2.0
Karamercan & Gainer 6	1979				1.5–47.4	.0–5.0				3/4	36. & 76.	reciprocating pump	h_p/h_s =0.9–8.0
Herndon, et al. 7	1980				6.6–28.0	.83–16.7	—			0.788	36.1	interrupter valve	h_p/h_s = 0.8–2.2

Table A-1 (continued)

b) Pulsating air flow over a flat plate.

Authors Ref.	Year	Heating	Re $\times 10^{-3}$	f, Hz	$\hat{V}/\bar{V}$ or $\hat{p}/\bar{p}$	T_w/T_b	p, psia	Test section d_1, in.	Test section L, in.	Pulsator	Results/notes
Bayley, et al. 8	1961	Electric	175	10-100				8in. x 3 1/8 in.		butter fly valve(rotating valve)	$Nu_x)_p/Nu_x)_s \approx 1.5$
Feiler and Yeager 9	1962		10-100	34-680				6in. x 4 in.		siren wheel	≈ 1.5
Feiler 10	1964		10-100	100			P_{atm}	1.0	19.5	siren	≈ 1.0
Miller 11	1969		120-480	3-200		T_w= 100 F		2 ft - 4.6 ft		rotating shutter valve	≈ 0.95-1.05

c) Pulsating air flow in tube in the range of frequency 0 - 40 Hz.

Authors Ref.	Year	Heating	Re $\times 10^{-3}$	f, Hz	$\hat{V}/\bar{V}$ or $\hat{p}/\bar{p}$	T_w/T_b	p, psia	Test section d_1, in.	Test section L, in.	Pulsator	Results/notes
Havemann, et al. 12	1956	steam	6-25	5-40				1.0	82.25	cam-driver poppet valve	$h_p/h_s = \pm 40\%$
Romie 13	1956	Electric	5	3.3-133	$\hat{V}/\bar{V}$ = 0.5~2.0	1.0	P_{atm}	0.98	25	rotating valve	Nu_p/Nu_s = 0.9-1.22 at L/D=12.0
Mueller 14	1957	steam	53-76	.038-0.248		1.0	P_{atm}	—	—	rotating variable area valve	Nu_p/Nu_s = 0.8 - 1.1
Chalitbhan 15	1959	steam heated air	7-200	2-15		1.0	90	.824	95.0	compressor	Nu_p/Nu_s = 1.1 - 1.8 (cooled air by water)
Mamayev, et al. 16	1976	electric	0.54-11	0.54-24	—			8mm	800 mm	magnetic valve	h_p/h_s = 0.9-1.3 for Re ≈ 3,000
Creff, et al. 25	1980	electric	80-200	0-36	$\hat{V}/\bar{V} \cong 0.36$			100 mm	6.5 m	reciprocating system	h_p/h_s {0.8-1.05; non-resonance; 0.8-1.8; resonance}

Table A-1 (continued)

d) Pulsating air flow in tube in the high frequency range, $f > 40$ Hz.

Authors Ref.	Year	Heating	Re $\times 10^{-3}$	f, Hz	$\hat{V}/\bar{V}$ OR $\hat{p}/\bar{p}$	T_w/T_b	p, psia	Test section d_i, in.	Test section L, in.	Pulsator	Results/notes
Hwu 17	1959	steam	2.59-5.92	198, 256, 322				0.745		acoustic vibration	$h_p/h_s = 1.2-1.5$
Lemlich & Hwu 18	1961	steam	0.56-5.9	198, 256, 322		1.0	P_{atm}	0.745	25	electro-magnetic driver	$h_p/h_s = 1.05 - 1.27$ for Re > 2,100
Jackson, et al 19	1961	steam	2.04-11.6	171, 221, 356		1.0	P_{atm}	3.85		horn-electro mag. driven	$Nu_x)_p/Nu_x)_s > 1.0$ or < 1.0 depending on velocity node
Jackson & Purdy 20	1965	steam	2 - 200	90-356		1.0	P_{atm}	3.86	120	acoustic vibration	$Nu_x)_p/Nu_x)_s > 1.0$ or < 1.0 depending on velocity node
Koshkin, et al. 21	1966	elec	10-100	50-460	$\hat{p}/\bar{p}$= 0.054-0.225	1.0	72-290	9.7 mm	1885 mm	rotating valve	$Nu_x)_p/Nu_x)_s = 0.9 - 2.25$
Bogdanoff 22	1967	steam	101	5 - 5000			54.7	1.5	$45 \frac{7}{16}$	siren wheel	$Nu_x)_p/Nu_x)_s > 1.0$ or < 1.0 depending on V-node or anti-node
Galitseyskiy, et al. 23	1969	elec	10-100	45-135	$\hat{p}/\bar{p}$= 0.0-0.25	1.2-1.5	72.5 - 290	9.7 mm	1885 mm	rotor - radial holes - motor driven	$Nu_x)_p/Nu_x)_s = 0.8 - 2.25$
Galitseyskiy, et al. 24	1969	elec	10-100	90-450	$\hat{p}/\bar{p}$= 0.0-0.25	1.2-1.6	72.5 - 290	9.7 mm	1885 mm	a rotor	$Nu_x)_p/Nu_x)_s = 0.85 - 2.25$

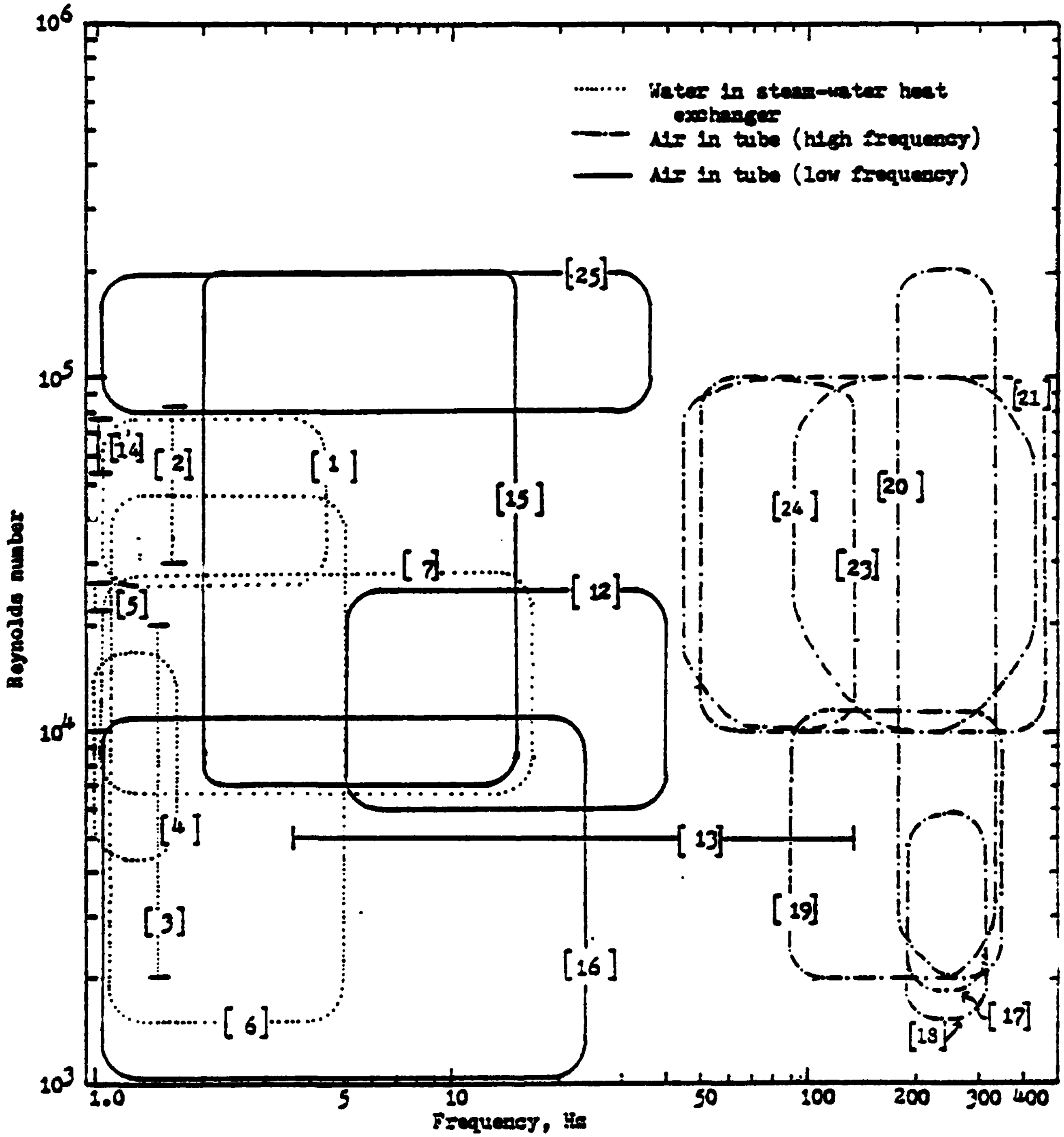

Figure A-1. Ranges of frequency and Reynolds number of experimental data on heat transfer to pulsating, turbulent flow.

I.C. Pulsating Air Flow in Tube in the Frequency Range 0-40 Hz

The results of measurements of heat transfer to pulsating air flow through a tube in the low frequency range are shown in Fig. A-2 and Fig. A-3. Half [12] [14] [15] of those experiments used steam-to-air heat exchangers which do not normally permit precise comparison, and the other experiments [13], [16], [25] used the tubes with electrical heating.

By using a tube heated with steam, Haveman et al. [12] (f=5-40 Hz, Re=6000-25,000) reported changes of heat transfer parameters from -40% to +40%; Chalitbhan [15] (f=0-15Hz, Re=7000-200,000) always showed an increase of heat transfer, as high as 100% at Re$\approx$10,000-50,000 and around 20% at Re=160,000-200,000; and Mueller [14] (f=0.038-0.248 Hz, Re=53,000-76,000) showed the average Nusselt number to be about 0-20% less than the corresponding steady flow, theoretically and experimentally. Because no information was given on the amplitude of the fluctuations and substantial experimental uncertainties were involved (generally, more than $\pm$10-30% for steady flow), it is very difficult to compare these results with other references.

Particularly, Chalitbhan calculated Nusselt numbers by modifying the Martinelli equation [42], and computed the Nusselt number of the pulsating flow by using the ratio of the pressure drop for pulsating flow to that for non-pulsating flow. He used a water-filled manometer for the pressure drop of the test

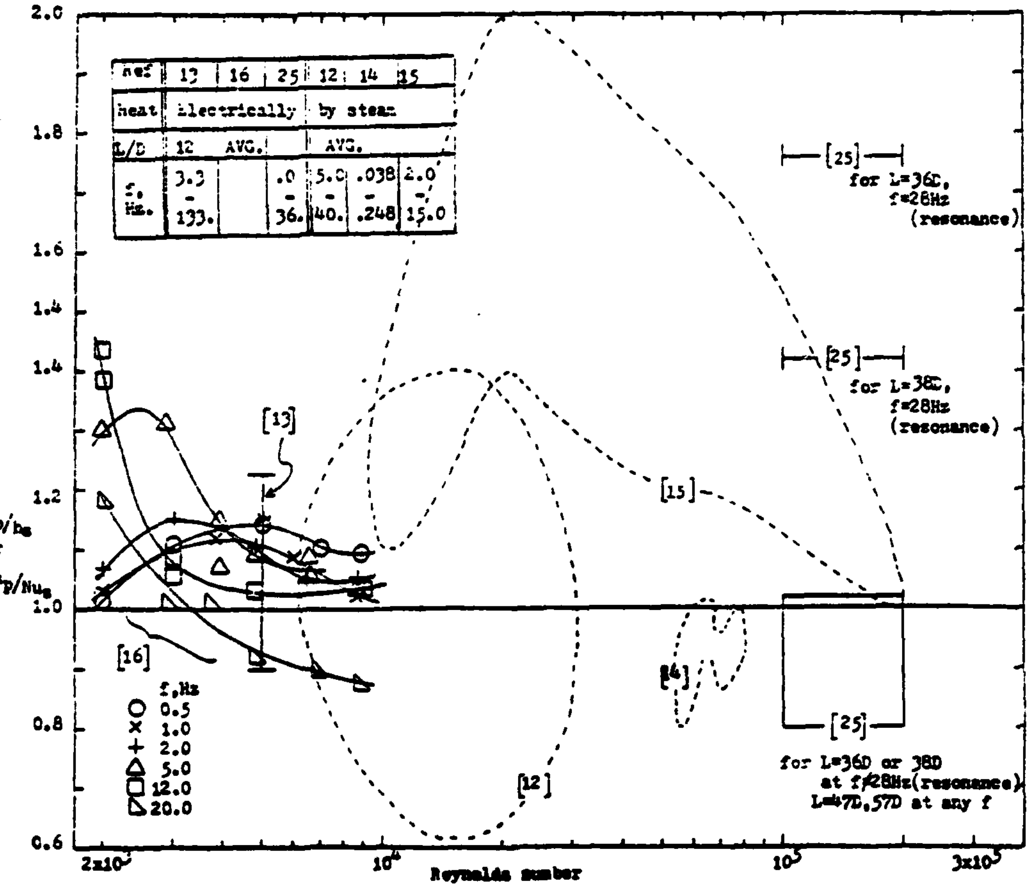

Fig. A-2. The effect of air velocity on heat transfer to pulsating, turbulent flow.

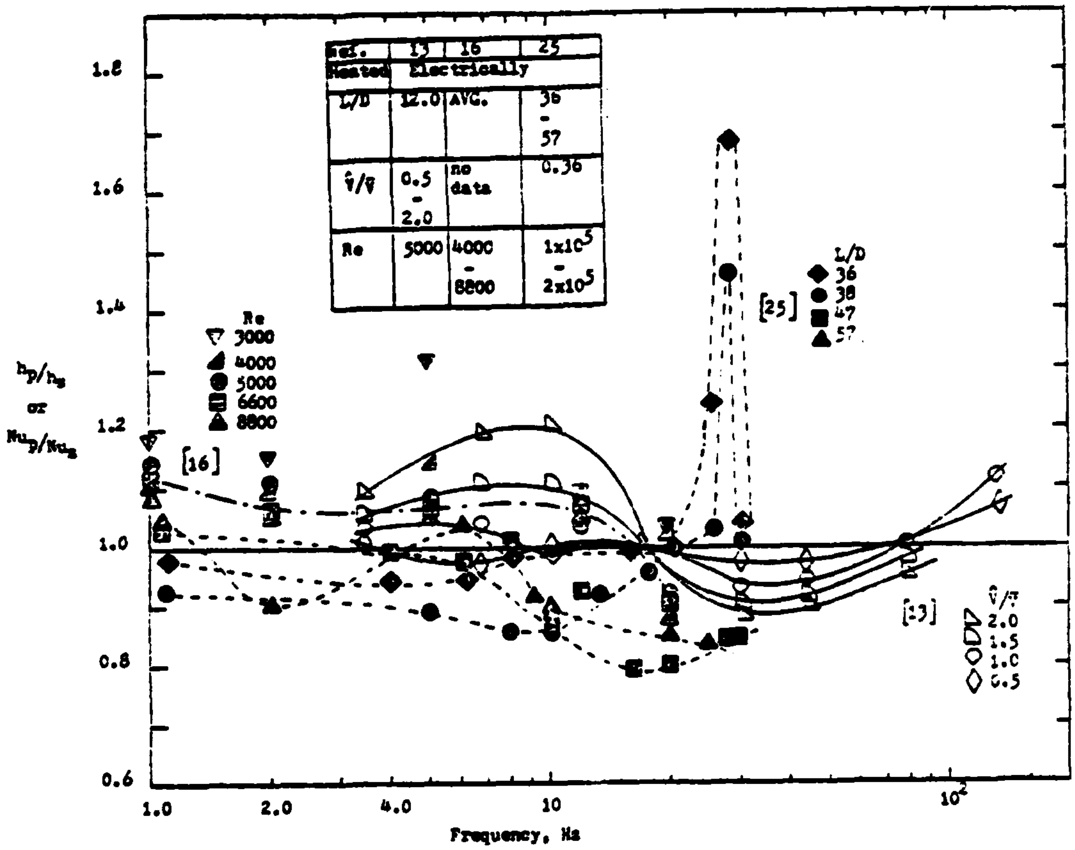

Fig. A-3. The effect of the frequency of induced fluctuations on heat transfer to pulsating, turbulent air flow.

section. So his results may have a large error as the values of pressure drop for pulsating flow cannot be measured accurately by inferential meter readings [43][44].

With electrical heating, Romie [13], Mamayev et al. [16] and Creff et al. [25] showed that heat transfer parameters of the pulsed flow are close ($\pm$20%) to those obtained in a steady flow, except for the resonance results of Ref. [25] (Fig. 3).

Romie [13] measured heat transfer data at a position 12 diameters downstream from the heated section entrance (Re=5000, f=3.3-133 Hz, $\frac{\hat{V}}{\bar{V}}$ =0.5-2.0) and showed the ratio of the Nusselt numbers of the pulsed flow to those of unpulsed flow increases above unity with increasing frequency ($\hat{V}/\bar{V} > 1.0$) then decreases to a value below unity, and then, at still higher frequencies, increases above unity. But as explained by Bogdanoff [22] for the high frequencies (f=75, 133 Hz), the oscillation amplitudes measured by a hot-wire would not be representative of conditions at the point where the heat transfer measurement was taken, because $\lambda/4$ becomes much shorter than the duct length and, hence, the velocity amplitudes at a point may not be representative of conditions existing all along the heated section.

Mamayev, et al. [16] carried out experiments (f=0.5-25 Hz, Re=540-11,000) and showed that the heat transfer coefficient averaged over the pipe length, is higher (0-15%) than in an equivalent non-pulsed flow except for f=20 Hz as shown in Figs. A-2 and A-3. The amplitude of fluctuations was not recorded. Their

effects of air velocity and the frequency on heat transfer to pulsed flow at Re=4,000-8,800 can be summarized as follows:

I. The effect of air velocity on heat transfer to pulsed flow

A) The critical values of Reynolds number, reflecting changes in flow modes, depend on f and shift toward lower values with an increase in f. This effect was not observed at $f \leq 2$ Hz.

B) At $Re > Re_{CR}$, the ratio of heat transfer coefficients drops exponentially and steeply with Re for f=5, 12, 20 Hz.

C) The ratio of heat transfer coefficients tends to unity at f=0.5 to 12 Hz, while at $f \geq 20$ Hz the pulsations have a negative effect on the heat transfer rate in turbulent flow.

II. The effect of the frequency on heat transfer

A) At Re=3000 to 4000, the ratio of heat transfer coefficients increases above f=5 Hz, and then asymptotically tends to unity.

B) At Re=5000-8800, this ratio has a peak at f=0.5 to 1.0 Hz and then decreases to unity.

C) No effect of flow fluctuations is observed at $f \approx 15$ Hz, while at f=15 to 24 Hz the heat transfer coefficients are smaller than for steady flow.

As shown in Fig. A-3, Romie and Mamayeu et al. showed no effects of flow fluctuation at a frequency near 15 Hz. Creff et al. [25],

(mean Re=10^5 -$2x10^5$, f=0-36 Hz, $\frac{\hat{V}}{\bar{V}}$ = 0.36), studied the frequency influence on the local heat transfer rates, and especially those due to acoustic resonance frequencies of the pipe. They showed that the local Nusselt numbers are close (+5.0~-20%) to those of the unpulsed flow at the same mean flow rate except near the resonance. For the resonance modes heat transfer increases about 75% at antinodes of the amplitude of the gas velocity as shown in Fig. A-3. Heat loss is less than or equal to 10% of total heat flux.

I.D. Pulsating Air Flow in Tube in the High Frequency Range, f > 40 Hz

Experimental investigations in the high frequency ranges which involved resonances [26] of the tube system were made by using a steam heated tube with acoustic vibrations (siren or horn) [17-20, 22] and by using an electrically heated tube with oscillations generated by a rotating valve [21, 23, 24].

Most of these results, generally, agreed that the effect of resonant fluctuations on heat transfer was found much greater than that of non-resonant pulsations. The effect increases as the amplitude of pulsations increases.

However, the effects of resonant fluctuations in heat transfer are uncertain because an increase in heat transfer was observed in some cases and a reduction in others, depending on the Reynolds number, node or antinode of standing-wave velocity along the length of pipe, pulsation amplitude, frequency, and so on.

Hwu and Lemlich [17, 18] showed an increase in the heat transfer coefficient up to 27% in the turbulent region, at frequencies which were resonances of the tube system allowing large amplitude oscillations to occur (Re=560-5,900, f=198, 256, 322 Hz). For pressure amplitude measurement a water manometer was used, so the amplitude data may not be accurate, as mentioned in Ref. [43, 44].

Jackson et al. [19, 20] studied air flow in a steam heated tube (Re=2000-200,000, f=90-356 Hz) at resonant frequencies. To measure the intensity of the oscillations induced by a horn, a microphone mounted on a rod was inserted into the duct from the upstream end. Typical heat transfer data are reproduced in Figs. A-4 - A-7, and are discussed by Bogdanoff [22] for a frequency of about 220 cps as follows:

1) At Reynolds numbers of 43,000 and above, the data behaves as exemplified by Fig. A-6, i.e., the general effect of oscillations is to reduce the heat transfer rates, the largest reductions appearing near the velocity antinodes, and relatively little effect in the regions of the velocity node.
2) As Reynolds number is decreased into the range 22,800-33,000 the effects of heat transfer become small and irregular although the sound pressure levels are diminished.
3) On further decrease of the Reynolds number into

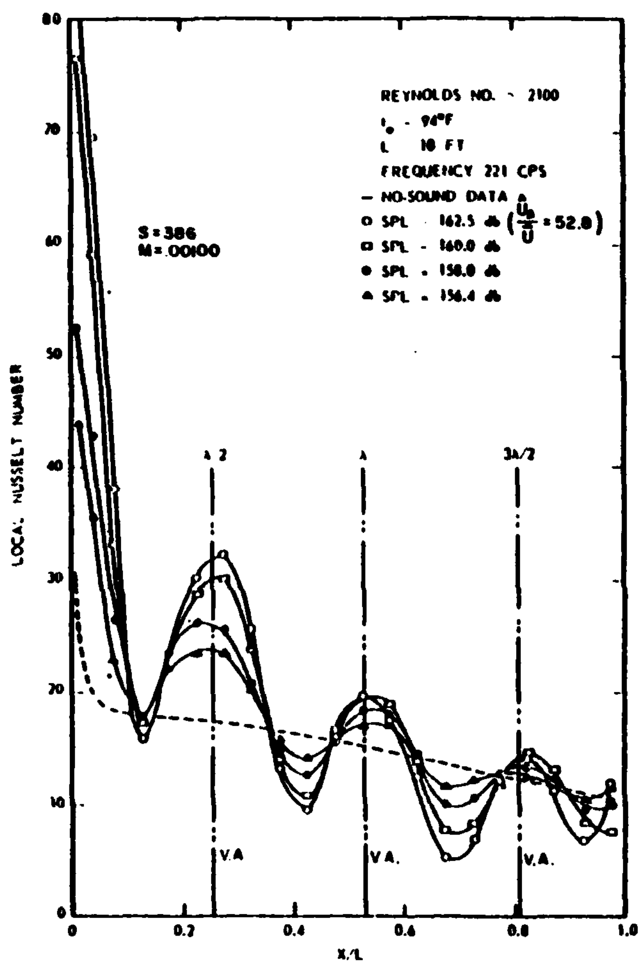

Fig. A-4. Effect of pulsations on local Nusselt numbers for various sound pressure levels, f = 221 Hz and Re = 2,100.

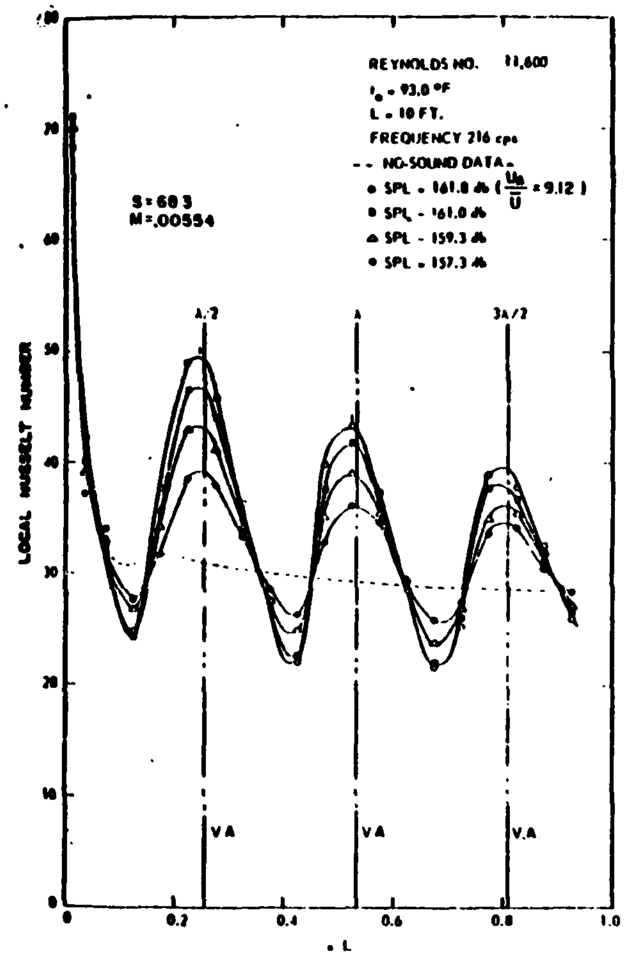

Fig. A-5. Effect of pulsations on local Nusselt numbers for various pressure levels, f = 216 Hz and Re = 11,600.

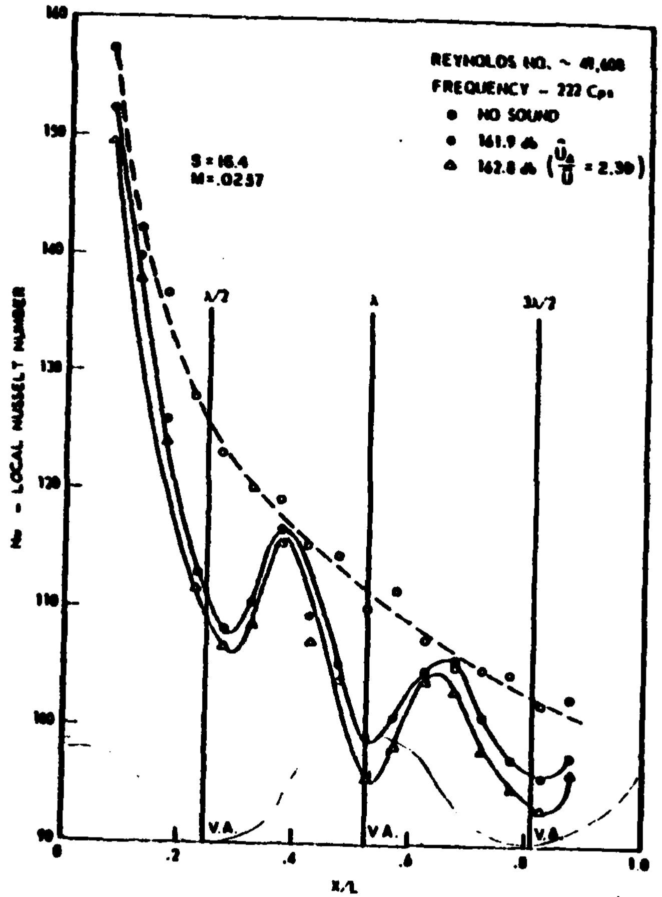

Fig. A-6. Effect of pulsations on local Nusselt numbers for various sound levels, f = 222 Hz and Re = 49,600.

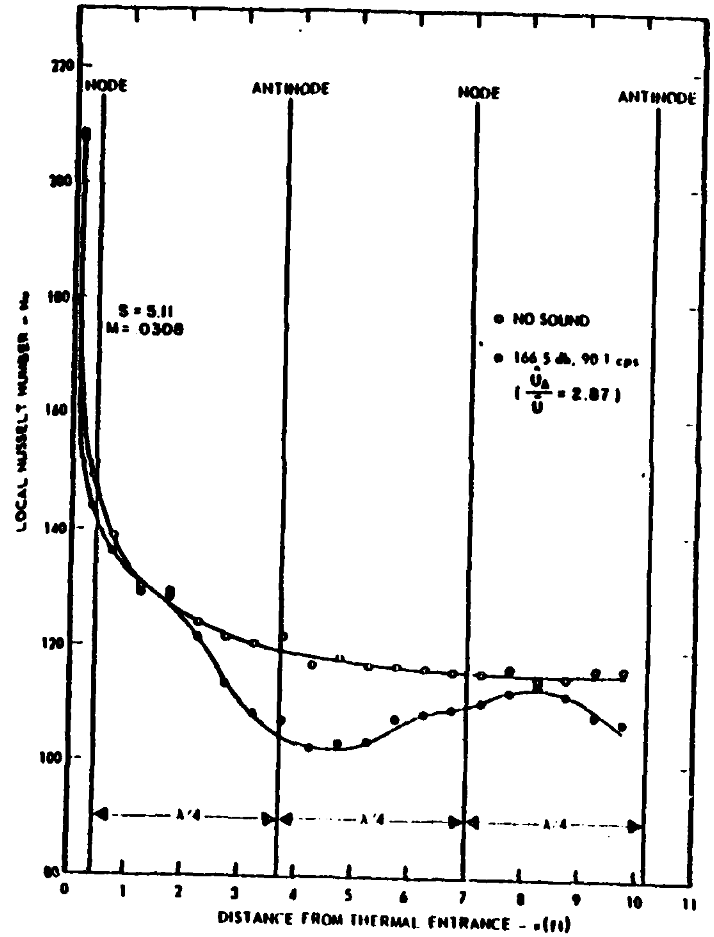

Fig. A-7. Effect of pulsations on local Nusselt numbers for f = 90.1 Hz and Re = 64,600.

the range 11,600-16,000, there is again, a strong effect of the oscillation on heat transfer as shown in Fig. A-5, i.e., increases in heat transfer at the velocity antinodes, decreases at the velocity nodes and an overall increase in heat transfer.

Bogdanoff [22] investigated air flow in a steam heated pipe at the resonant frequency which was induced by a siren wheel. Measurement of the amplitude of the pressure fluctuations was taken with a pressure transducer just upstream of the siren wheel which was at the end of tube. The experimental results for 7 runs at the 9th harmonic and 1 run at the 13th harmonic are reproduced in Figs. A-8 - A-15.

The quantity $\tilde{U}_A/\bar{U}$, the instantaneous velocity which would be required to cause a pressure fluctuation $\tilde{p}/\bar{p}$, was computed from a simple-wave formula for acoustical waves in a duct without friction losses [26],

$$\tilde{U}_A/\bar{U} = \tilde{p}_N/\bar{p} * 1/\gamma M \qquad (A.1)$$

where the pertinent nomenclature may be summarized as:

$S_a = \omega D/\bar{U}_a$, Strouhal number upstream of the heated section

$\tilde{p}_N$ = root mean square pressure fluctuation

$\tilde{U}$ = r.m.s. velocity fluctuation at pipe center-line

$\hat{U}$ = peak-to-peak velocity at pipe center-line, or in free stream

$\bar{p}$, $\bar{U}$ = mean pressure, velocity.

From the assumption of sinusoidal pressure waves, $\hat{U}_A/\bar{U}$ is roughly

$$\hat{U}_A/\bar{U} \approx 2\sqrt{2}\,\tilde{U}_A/\bar{U} \approx 2.83\,\tilde{U}_A/\bar{U} \qquad (A.2)$$

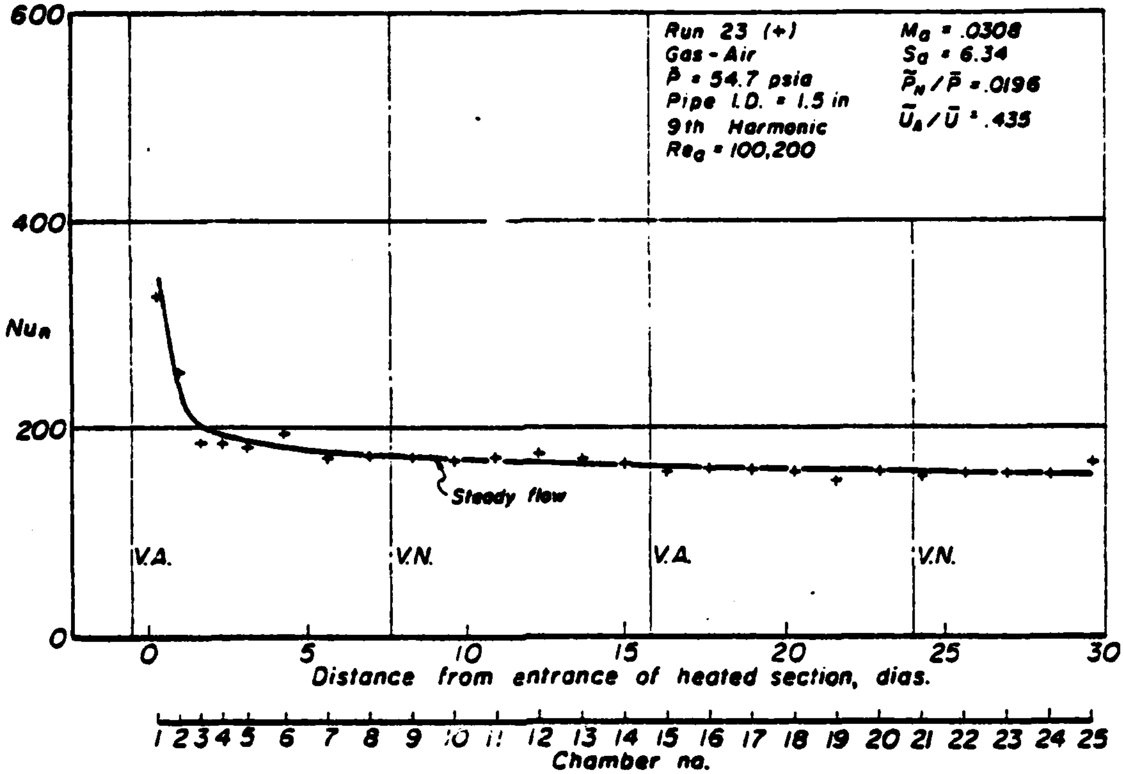

Figure A-8. Effect of pulsations on local Nusselt numbers for $\tilde{p}/\bar{p}$ = 0.0196 from Bogdanoff [22].

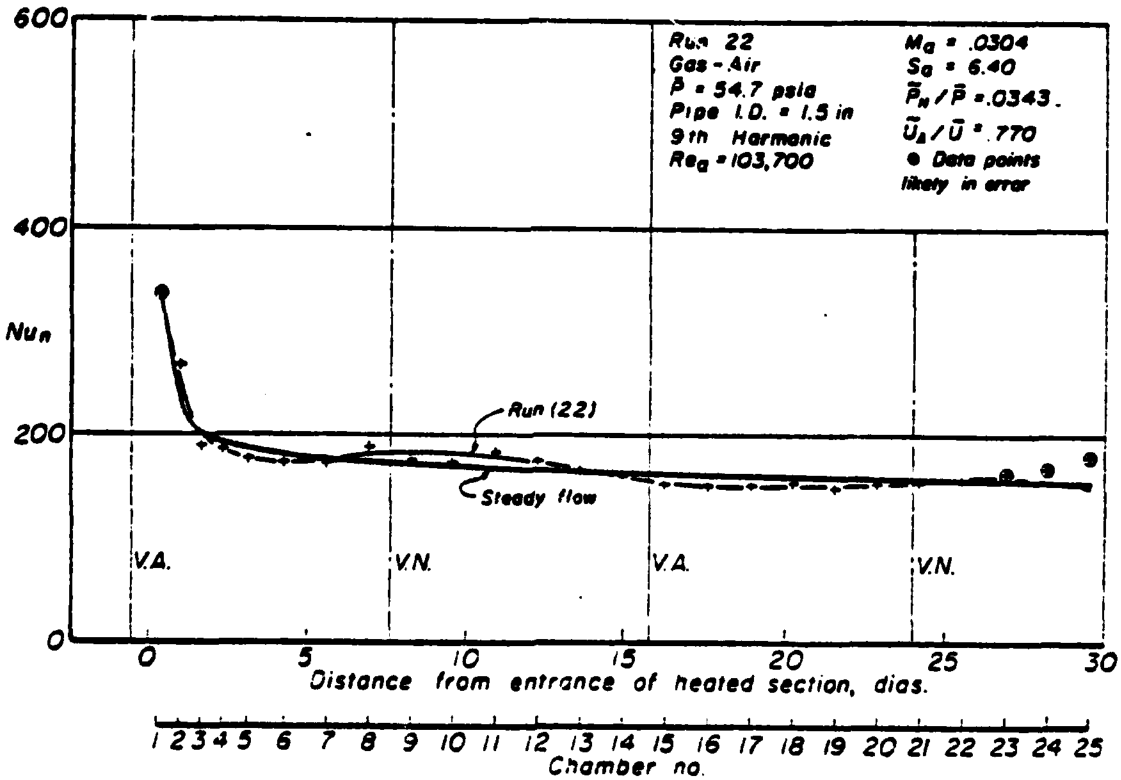

Figure A-9. Effect of pulsations on local Nusselt numbers for $\tilde{p}/\bar{p}$ = 0.0343 from Bogdanoff [22].

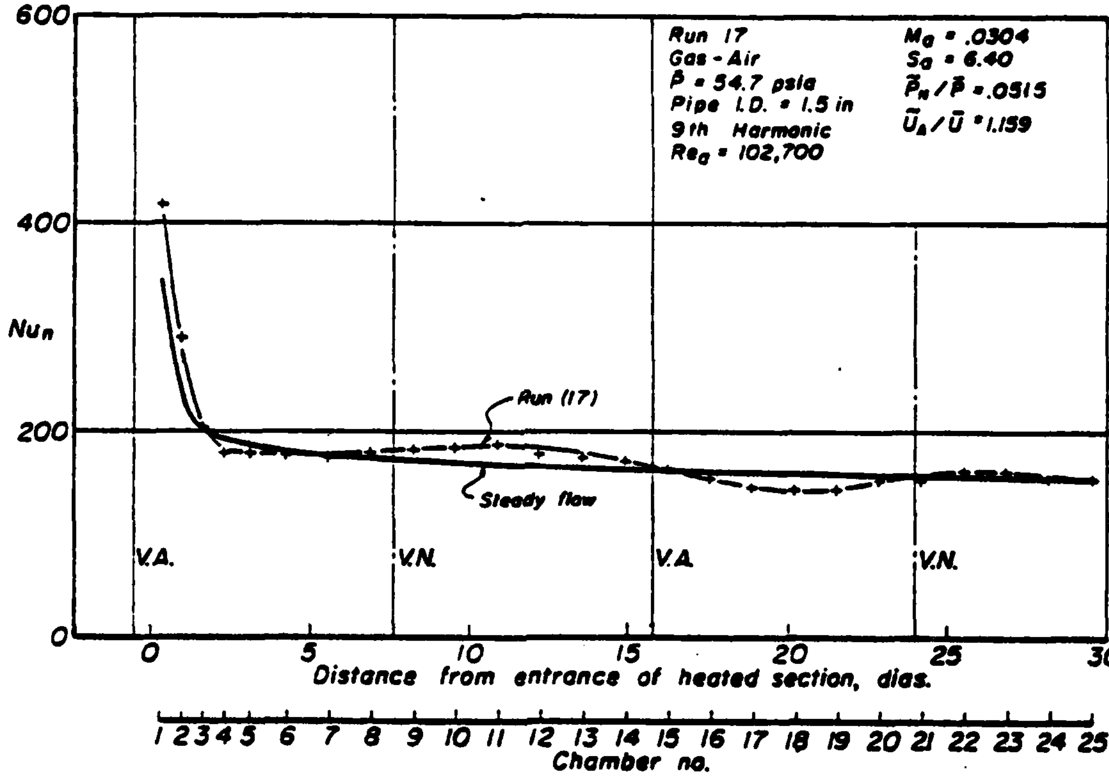

Figure A-10. Effect of pulsations on local Nusselt numbers for $\tilde{p}/\bar{p}$ = 0.0515 from Bogdanoff [22].

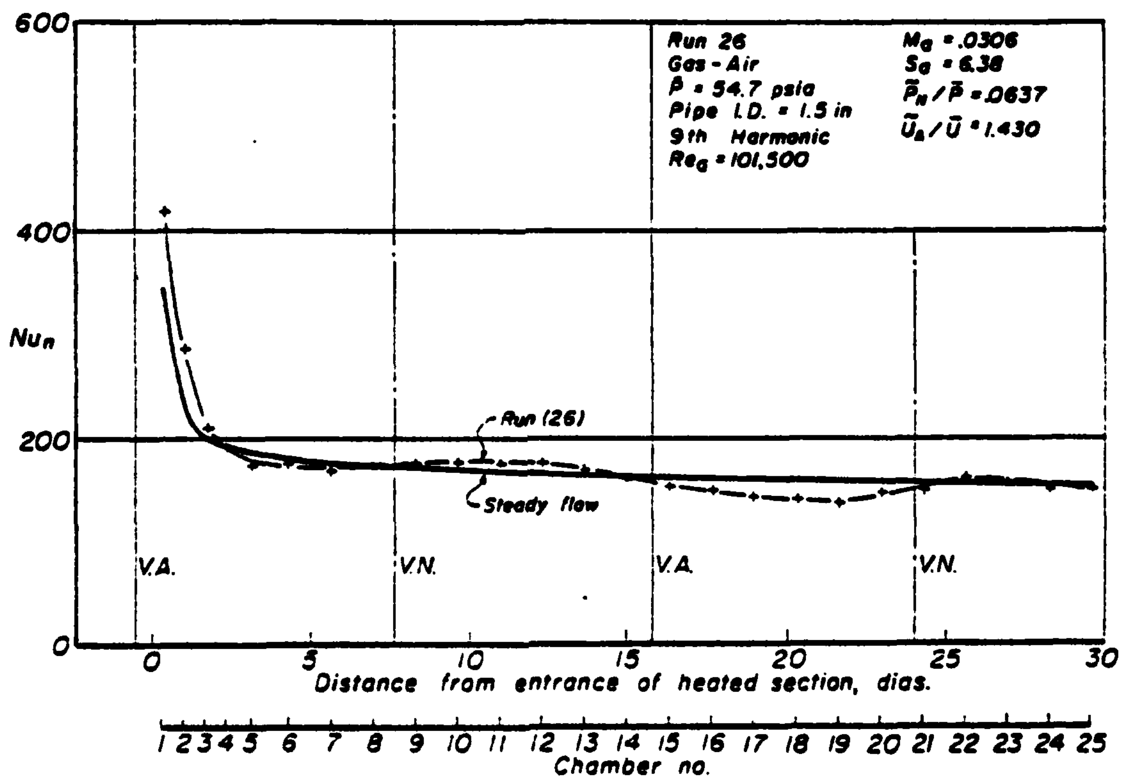

Figure A-11. Effect of pulsations on local Nusselt numbers for $\tilde{P}_N/\bar{p}$ = 0.0637 from Bogdanoff [22].

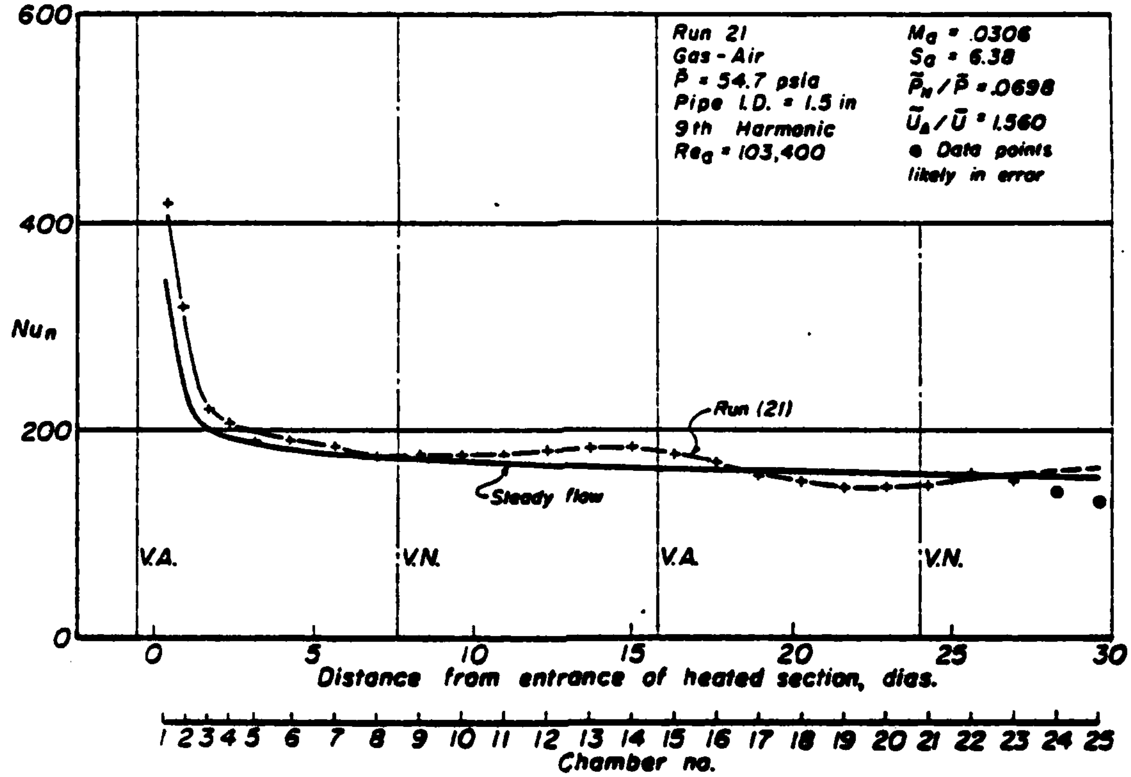

Figure A-12. Effect of pulsations on local Nusselt numbers for $\tilde{P}_N/\bar{p}$ = 0.698 from Bogdanoff [22].

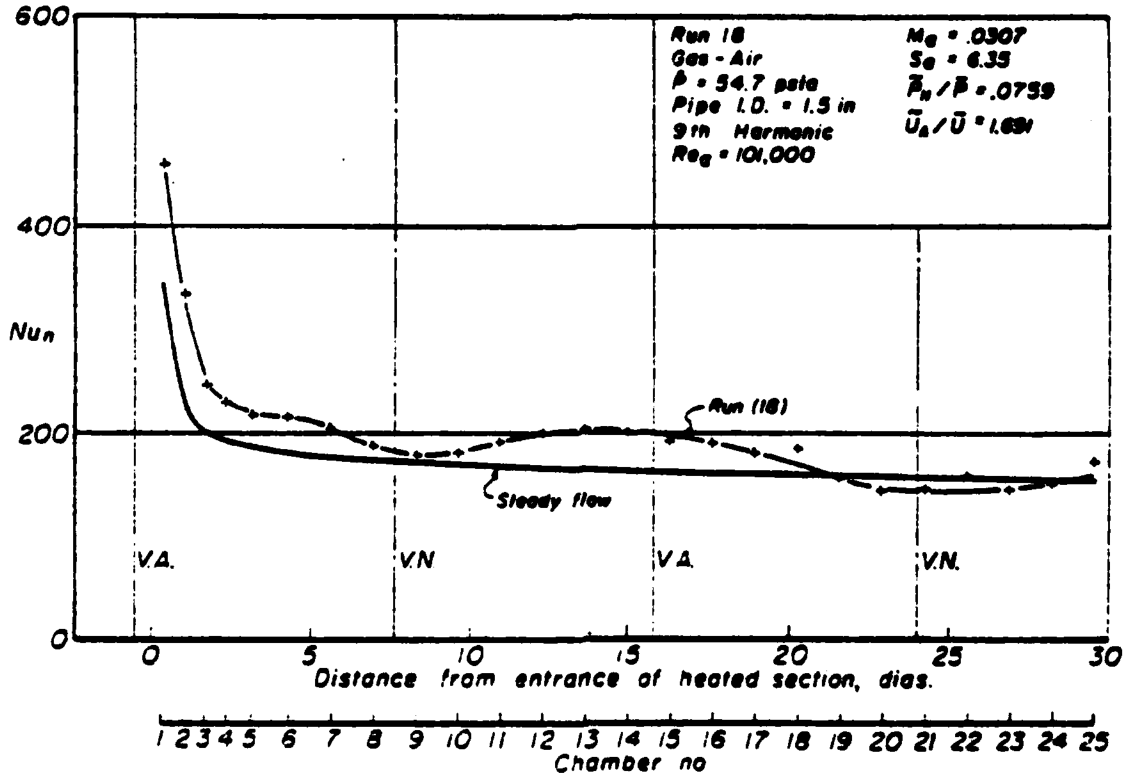

Figure A-13. Effect of pulsations on local Nusselt numbers for $\tilde{P}_N/\bar{p}$ = 0.0759 from Bogdanoff [22].

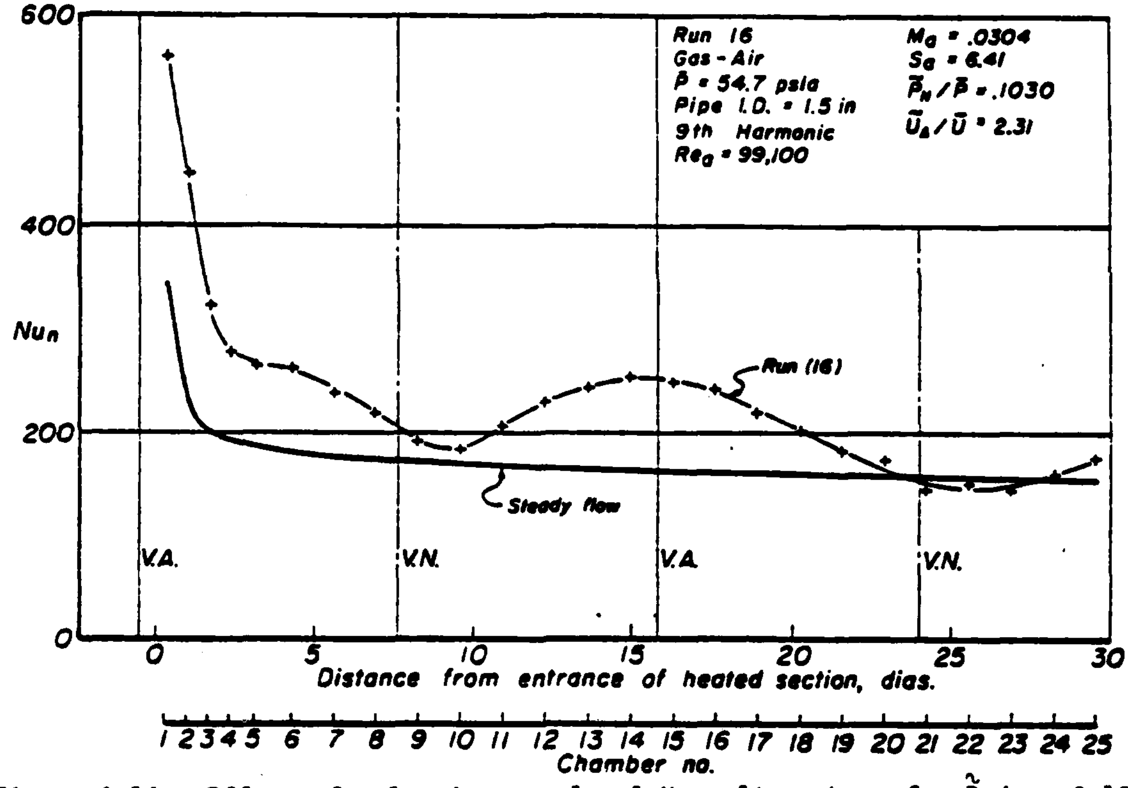

Figure A-14. Effect of pulsations on local Nusselt numbers for $\tilde{P}_N/\bar{p}$ = 0.1030 from Bogdanoff [22].

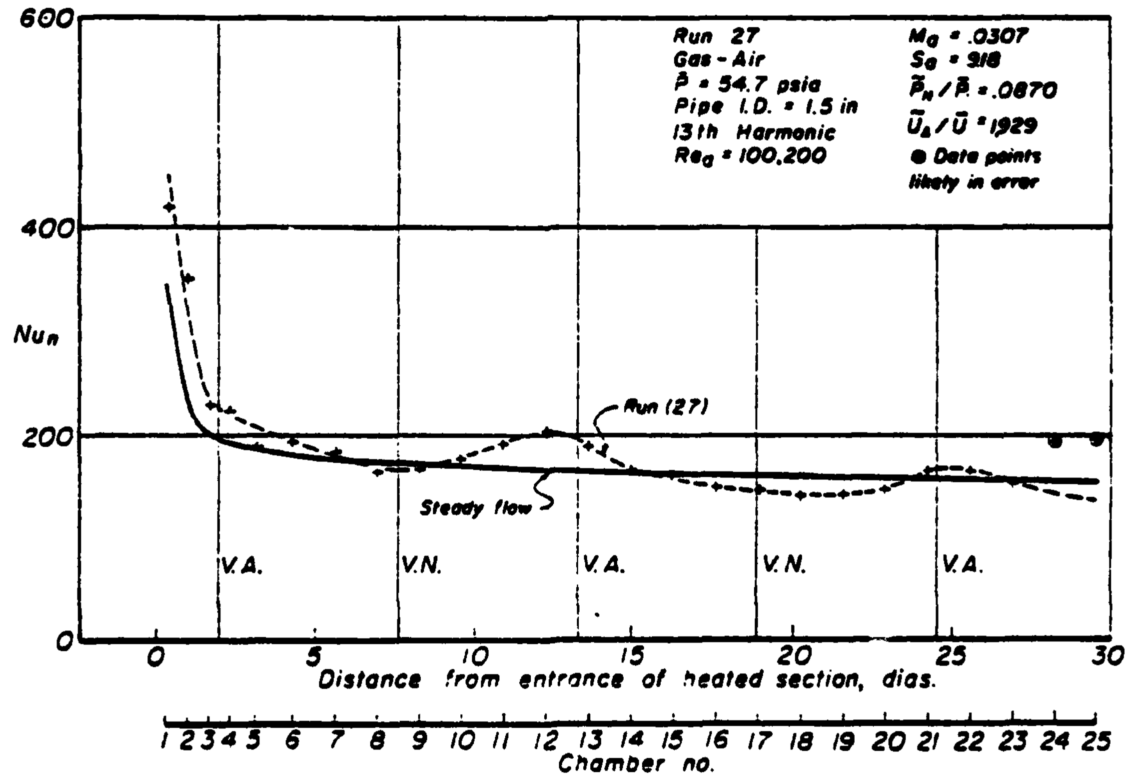

Figure A-15. Effect of pulsations on local NUsselt numbers for $\tilde{P}_N/\bar{p}$ = 0.087 from Bogdanoff [22].

His results can be summarized as follows:

1) For all runs, Re $\approx 10^5$, and M = 0.03, $S_a \approx 6.4$ for all 9th harmonic runs and S_a=9.18 for the 13th harmonic run. From Fig. A-8 we see that oscillations have little effect on heat transfer at $\tilde{U}_A/\bar{U} \approx 0.4$.

2) At $\tilde{U}_A/\bar{U} \approx 0.8$, the oscillations produce a noticeable effect on the heat transfer. The maxima of heat transfer are downstream of the velocity nodes, the minima downstream of antinodes and there is little overall change of heat transfer.

3) As the oscillating amplitude increases ($\tilde{U}_A/\bar{U} \approx 1.2$, 1.4, 1.56), the amplitude of the variation of heat transfer increases, and the maxima and minima move downstream, but the overall heat transfer changes are small.

4) Increasing the oscillation amplitude still further ($\tilde{U}_A/\bar{U}$ = 1.7, 2.3) moves the maxima and minima even further downstream (the maxima is near the velocity antinode, and the minima are slightly downstream of velocity nodes), increases the amplitude of the heat transfer fluctuations, and produces substantial overall increases in heat transfer rates (especially for $\tilde{U}_A/\bar{U}$ = 2.3).

5) The test taken at the 13th harmonic shows fluctuations of heat transfer whose maxima and minima are located similarly to those at the 9th harmonic for comparable $\tilde{U}_A/\bar{U}$ values ($\tilde{U}_A/\bar{U} \approx 1.9$) but shows considerably smaller overall increases in

heat transfer.

Koshkin et al. [21] and Galitseyskiy et al. [23, 24] investigated heat transfer to pulsating air flow in an electrically heated tube. Local heat transfer measurements were taken at various points over a heated section (Re = 10^4-10^5, p = 72-290 psia, $T_w/T_b \approx$ 1.2-1.6 [23, 24] or 1.0 [21], $\frac{\hat{P}}{\bar{P}}$ = 0-0.25). Oscillations were generated by a rotating valve upstream of the heated section. The relative amplitude of pressure pulsations was taken at the experimental tube inlet. Typical heat transfer data are reproduced in Fig. A-16. These results can be summarized as follows:

(1) Resonance pressure pulsations of the fluid in a pipe appreciably affect the heat transfer near standing-wave velocity maxima; the effect increases with an increase in the amplitude of the pressure pulsation.

(2) In the experiments the heat transfer coefficient in the first standing-wave velocity maxima was 2-3 times greater than that for steady state.

(3) As a result of dissipation of the pulsation energy, the heat transfer coefficient decreases along the pipe, i.e., the closer the velocity maximum to the pipe inlet the higher the heat transfer.

(4) The distribution of the local heat transfer coefficient along the length of the pipe is similar to the kinetic

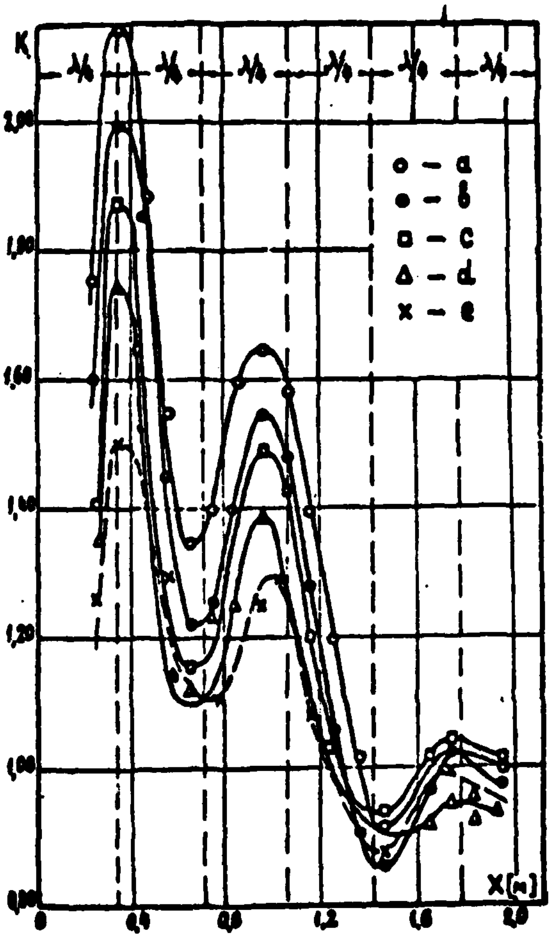

Figure A-16. Heat transfer distribution ($K = Nu_p/Nu_s$) along the experimental tube with $n = 3$ for various values of $\left(\frac{\Delta p}{\bar{p}}\right)_o$; $Re = 10^4 \div 10^5$; a - $\left(\frac{\Delta p}{\bar{p}}\right)_o = 0.225$; b - $\left(\frac{\Delta p}{\bar{p}}\right)_o = 0.184$; c - $\left(\frac{\Delta p}{\bar{p}}\right)_o = 0.11$, d - $\left(\frac{\Delta p}{\bar{p}}\right)_o = 0.090$, e - $\left(\frac{\Delta p}{\bar{p}}\right)_o = 0.054$.

(from Koshkin et al. [21])

energy distribution along the standing wave.

(5) The number of heat transfer maxima and minima is determined by the number of the resonant harmonics.

(6) The effects of the Reynolds number in the range of 10^4-10^5 and of the number of the resonance harmonic on the relative heat transfer in the experiments are insignificant as under steady-state conditions, i.e., lie within the limits of experimental accuracy ($\pm$ 10%).

II. Theoretical Studies and Quasi-steady Conditions for Pulsating Turbulent Flow

Although the effects of the flow pulsation on heat transfer characteristics for turbulent flow have been studied over the past 40 years, there are few theoretical analyses in the literature [14,29,31] for turbulent pulsating flow. The present work is limited to demonstrate simply the results of the theoretical analyses rather than a comprehensive explanation of these studies.

Barnett and Vachon [29] presented an analysis for the turbulent fully developed flow of a fluid in a tube undergoing harmonic oscillations parallel to its centerline with the governing parameters: Reynolds and Prandtl numbers, non-dimensional frequency, and the dimensionless amplitude of vibration. By assuming the turbulent diffusion of momentum and energy were unaffected by this motion, they predicted significant increases in heat transfer coefficients only at low frequencies and for large amplitudes.

The Nusselt number decreases at high frequencies with respect to the corresponding steady flow value. The effects of pulsating flow on heat transfer are amplified with Prandtl numbers below unity.

References [3, 4, 5, 14, 22, 30, 31, 32] discussed the effects of pulsatile flow to heat transfer, and some provided results for quasi-steady conditions; i.e., frequency low enough that heat transfer coefficient at any instant in pulsating flow can be predicted by the usual steady state correlations.

Park, Taylor and McEligot [33] summarized the comments of Smolderen [34] about the governing parameters of non-steady flow as follows:

1) Strouhal number: $Str_L = \frac{f_L}{V}$ (A.3)

2) For acoustic disturbances, the ratio of the length of the flow path to the wave length of sound waves:

$$L/\lambda = \frac{Lf}{a_o} = M \cdot Str_L \qquad (A.4)$$

3) For consideration of viscous effects, non-dimensional frequency:

$$\alpha = L\sqrt{2\pi f/\nu} \left(=\sqrt{Re_L \cdot Str_L}\right) \qquad (A.5)$$

If $Str_L \ll 1$, the unsteady term in the governing equation becomes negligible relative to convective terms, and the flow can be treated as quasi-steady. If $\frac{L}{\lambda}$ and α are small, the flow is considered as quasi-steady for acoustical and viscous effects, respectively.

Mueller [14] showed analytical and experimental results of pulsating turbulent pipe-flow heat transfer in a quasi-steady condition. For quasi-steady flows which are non-reversing, his analysis reported a slightly lower average Nusselt number must be expected than for steady flow. Experimental results (Re=53,000-76,000, f=0.038-0.248 Hz, steam heated tube) showed the average Nusselt number to be less, 0-20%, than the corresponding steady-flow Nusselt number.

Lemlich [3] showed that for fully developed flow with constant properties, if $h_s \sim V^n$, the improvement ratio or enhancement due to pulsation would be

$$\bar{h}_p/h_s = \frac{(2\pi)^{n-1}\int_0^{2\pi} V^n(\omega t)\, d(\omega t)}{\left[\int_0^{2\pi} V(\omega t)\, d(\omega t)\right]^n} \qquad \text{(A.6)}$$

By similar method, Baird et al. [4, 5] and Bogdanoff [22] showed that the time-average ratio of heat transfer can be shown to be,

$$\overline{Nu}_p/Nu_s = \frac{1}{2\pi}\int_0^{2\pi} \left|1 + \frac{\hat{V}}{2\bar{V}} \sin\omega t\right|^{0.8} d(\omega t) \qquad \text{(A.7)}$$

with the assumptions of $h_s \sim V^{0.8}$ for steady turbulent flow in a tube and a sinusoidal variation of velocity,

$$V = \bar{V}\,(1 + \frac{\gamma}{2} \sin \omega t) \qquad \text{(A.8)}$$

Typical results of Eq. A.7 which are independent of frequency are shown in Fig. A-17. Experimental results by Baird et al. [4, 5] showed that $\bar{h}_p/h_s$ does not fall significantly below unity at low values of $\hat{V}/\bar{V}$, and that the quasi-steady flow theory, while not

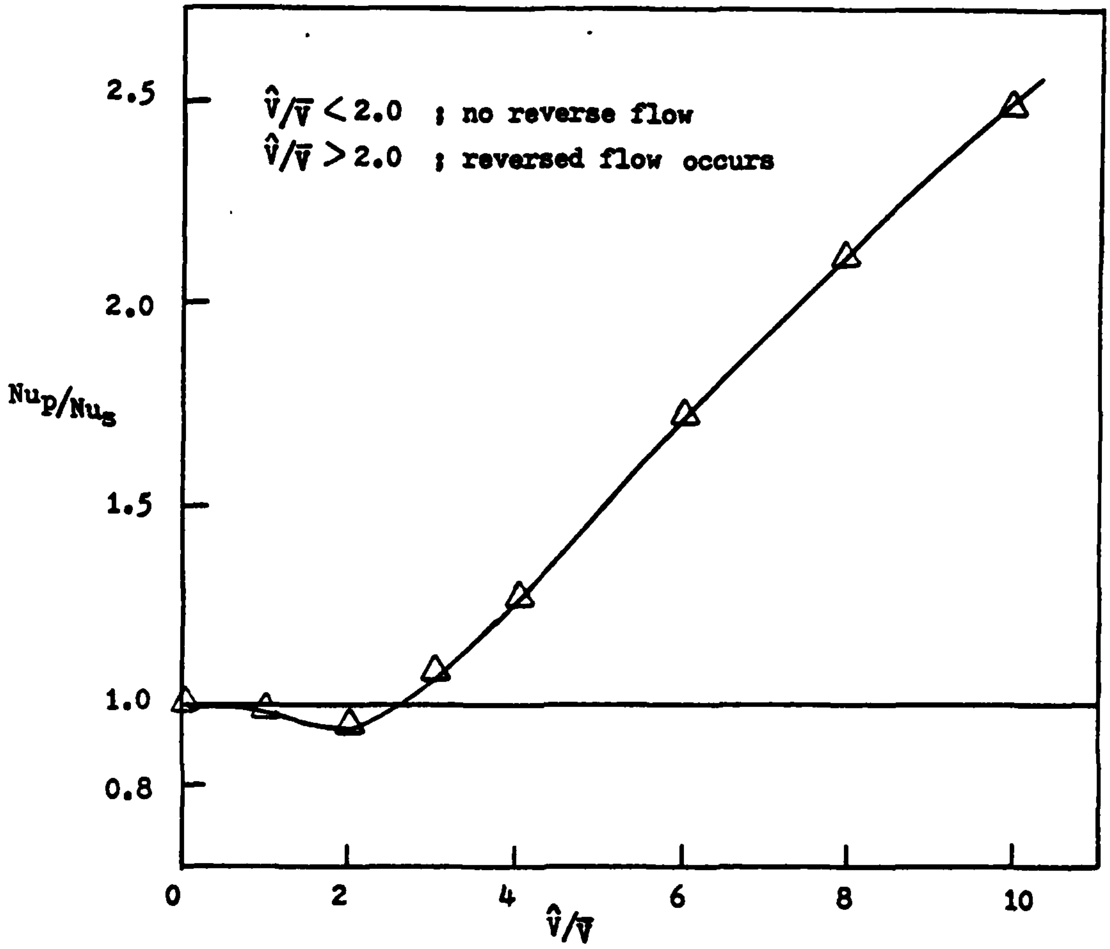

Figure A-17. Effect of pulsations on heat transfer for quasi-steady conditions (from Bogdanoff [22]).

completely satisfactory, does predict approximately the effects of flow pulsation at high values of $\hat{V}/\bar{V}$.

It is shown in Fig. A-17 that significant improvements in heat transfer are not obtained until $\hat{V}/\bar{V}$ exceeds approximately 3.0. Many papers [4, 14, 28, 31, 32, 35, 36] discussed different conditions for the quasi-steady state approximation to be valid, e.g., $\alpha < 7.4$ [4], $\alpha^2 \lesssim 0.1\ Re_D$ [35,36].

III. Summary of Literature Survey

The results presented in this literature survey show that different studies of heat transfer in pulsed flow have provided their contributions by showing the existence of specific phenomena appropriate to those flows. Those contributions have shown that the heat transfer rate increases or decreases in comparison to non-pulsed flow for various experiment conditions, by variation of the following quantities:

1) frequency
2) amplitude of oscillation
3) mean Reynolds number
4) mode of generation of pulsations
5) acoustic resonance of the system
6) antinode or node of the flow velocity
7) and so on.

It is not immediately apparent which of the parameters are most important in determining the nature of the effects of the

pulsations on heat transfer. It is likely that different parameters will dominate in different ranges. The analyses generally predict only a slight modification of heat transfer parameters in pulsating turbulent flow whereas experiments have found larger effects.

Therefore, it is important to measure the heat transfer parameters in typical flows where data are not available in order to test the analytical predictions for normal operating conditions. Also, we should look for the parameters which most influence the heat transfer in pulsating turbulent flows. This is the task recommended for the current and future studies.

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RUN 806H, DATE 8/01/81, GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 77.7 F, TOUT = 263.5 F, MASS FLOW RATE = 40.4 LB/HR, I = 93.8 AMPS, E = 6.064 VOLTS
PR,IN = .719, GR/RESQ = .212E-02, MACH(2) = .118, MACH(16) = .134, T,SURR = 108.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	207.1	1.244	60073.	-.123	310.67	31441.0	.001731
3	.3	249.8	1.323	60006.	.467	140.45	18847.2	.001037
4	.5	278.9	1.375	59933.	.156	152.93	23940.9	.001318
5	.8	296.5	1.406	59860.	.065	153.41	26062.0	.001435
6	1.3	319.3	1.444	59709.	.039	143.16	26763.6	.001473
7	2.2	340.9	1.477	59470.	.025	134.00	27154.8	.001495
8	4.3	372.7	1.516	58875.	.024	121.35	27265.0	.001501
9	7.7	400.3	1.536	57990.	.025	112.66	27278.3	.001501
10	10.8	416.2	1.536	57201.	.026	108.86	27284.9	.001502
11	17.4	443.8	1.528	55651.	.029	103.08	27255.0	.001500
12	23.9	467.4	1.515	54198.	.034	98.82	27178.6	.001496
13	30.5	485.5	1.493	52810.	.037	96.75	27143.9	.001494
14	37.0	504.8	1.474	51545.	.040	94.64	27094.3	.001491
15	43.5	522.3	1.455	50378.	.043	93.17	27048.1	.001489
16	48.0	535.8	1.444	49629.	.046	91.71	27002.7	.001486
17	52.4	547.4	1.432	48918.	.048	90.79	26965.4	.001484
18	56.6	558.3	1.421	48273.	.101	85.67	25682.9	.001414
19	58.6	531.2	1.373	48026.	.549	67.72	18231.4	.001004
20	59.3	447.3	1.254	47976.	-.033	158.20	29018.9	.001597

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	56.9	-.17	76.6	-.596E-01
2	54.1	56.2	1.43	249.4	.535E+00

RUN 807H, DATE 8/01/81, GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 78.6 F, TOUT = 257.5 F, MASS FLOW RATE = 41.6 LB/HR, I = 93.4 AMPS, E = 6.062 VOLTS
PR,IN = .719, GR/RESQ = .205E-02, MACH(2) = .118, MACH(16) = .134, T,SURR = 108.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	204.9	1.236	61809.	-.115	311.94	30872.1	.001647
3	.3	247.0	1.316	61743.	.446	144.06	18954.3	.001011
4	.5	273.4	1.363	61670.	.121	161.49	24514.8	.001306
5	.8	292.0	1.395	61597.	.080	153.47	25466.7	.001358
6	1.3	313.3	1.431	61448.	.036	146.18	26569.2	.001418
7	2.2	334.0	1.462	61212.	.025	136.76	26930.3	.001437
8	4.3	364.4	1.500	60623.	.023	124.07	27037.0	.001442
9	7.7	391.1	1.520	59746.	.024	115.23	27049.6	.001443
10	10.8	406.6	1.521	58964.	.025	111.35	27056.5	.001443
11	17.4	433.8	1.515	57423.	.028	105.38	27028.3	.001442
12	23.9	456.5	1.502	55977.	.033	101.19	26960.9	.001438
13	30.5	474.2	1.481	54584.	.035	99.05	26929.4	.001436
14	37.0	492.7	1.464	53320.	.038	97.02	26885.9	.001434
15	43.5	510.2	1.446	52140.	.041	95.37	26841.7	.001432
16	48.0	522.7	1.435	51390.	.044	94.06	26804.7	.001430
17	52.4	534.9	1.425	50676.	.046	92.92	26765.5	.001425
18	56.6	545.2	1.415	50028.	.097	87.95	25540.9	.001362
19	58.6	520.4	1.370	49778.	.525	69.90	18341.6	.000976
20	59.2	438.3	1.252	49727.	-.033	160.61	28752.0	.001534

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	58.5	-.15	77.5	-.592E-01
2	54.1	57.8	1.42	243.8	.541E+00

APPENDIX B: EXPERIMENTAL RESULTS

Table B-1. Summary of experimental conditions

Run	Frequency (Hz)	α	$\Delta p/\bar{p}$	$Re_i \times 10^{-4}$	$(T_w/T_b)_{max}$	M_{TC16}
805	2.10	5.35	0.13	6.14	1.53	0.135
806	--	--	--	6.00	1.54	0.134
807	--	--	--	6.18	1.52	0.134
808	3.15	6.18	0.26	5.52	1.51	0.135
809	--	--	--	5.43	1.52	0.135
810	--	--	--	5.59	1.51	0.135
811	3.56	4.31	0.20	1.88	1.50	0.111
812	--	--	--	1.91	1.49	0.111
813	--	--	--	1.90	1.49	0.110
814	2.84	7.08	0.09	1.93	1.51	0.033
815	--	--	--	1.94	1.48	0.033
816	--	--	--	1.94	1.48	0.033
817	2.80	7.17	0.15	3.76	1.51	0.061
818	--	--	--	3.84	1.49	0.061
819	--	--	--	3.79	1.49	0.061
820	2.71	7.18	0.26	5.78	1.88	0.097
821	--	--	--	5.82	1.91	0.095
822	--	--	--	5.90	1.89	0.095
823	2.56	7.03	0.29	9.65	1.49	0.145
824	--	--	--	10.22	1.48	0.142
825	--	--	--	9.93	1.49	0.143
826	2.81	6.65	0.35	7.69	1.49	0.143
827	--	--	--	7.85	1.49	0.140
828	--	--	--	7.64	1.49	0.140
829	2.54	7.53	0.28	9.50	2.20	0.140
830	--	--	--	9.61	2.18	0.140
831	--	--	--	9.43	2.19	0.140
832	2.84	7.41	0.27	7.55	2.28	0.131
833	--	--	--	7.48	2.27	0.139
834	--	--	--	7.60	2.26	0.139
835	2.94	6.68	0.28	7.74	1.27	0.141
836	--	--	--	7.82	1.26	0.139
837	--	--	--	7.72	1.26	0.139

Table B-1. Summary of experimental conditions - continued

Run	Frequency (Hz)	α	$\Delta p/\bar{p}$	$Re_i \times 10^{-4}$	$(T_w/T_b)_{max}$	M_{TC16}
838	3.00	7.27	0.15	3.59	1.24	0.056
839	--	--	--	3.58	1.23	0.056
840	2.78	4.87	0.27	3.94	1.22	0.129
841	--	--	--	3.95	1.22	0.130

Table B-2. Tabulated data

The headings used in the following listings of the heated flow data and their definitions are below.

Heading	Definition
TIN	Inlet mixer temperature
TOUT	Calculated exit temperature
I	Alternating current
E	Voltage drop between voltage taps
PR, IN	Inlet Prandtl number
GR/RESQ	Ratio of Grashof number to the square of the Reynolds number
MACH(2)	Mach number at thermocouple 2
MACH(16)	Mach number at thermocouple 16
T,SURR	Temperature of surroundings
TC	Thermocouple number
X/D	Axial position, corresponds to x/D in text
TW	Inside tube wall temperature, °F
TW/TB	Wall-to-bulk temperature ratio
HL/QGAS	Ratio of heat loss to heat flux to gas
QGAS	Heat flux to gas
Q^+	Non-dimensional turbulent heat flux parameter. Corresponds to q^+ in text
PT	Pressure tap: 1-near inlet, 2-near exit
TB	Bulk static temperature
PRESS DEFECT	$\rho_i g_c (p_i - p)/G^2$

RUN 305H, DATE 8/01/81, GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 81.2 F, TOUT = 262.0 F, MASS FLOW RATE = 41.5 LB/HR, I = 93.8 AMPS, E = 6.084 VOLTS
PR,IN = .719, GR/RESQ = .203E-02, MACH(2) = .119, MACH(16) = .135, T,SURR = 105.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	206.2	1.235	61412.	-.121	319.02	31375.0	.001670
3	.3	248.9	1.313	61345.	.464	143.59	18884.4	.001005
4	.5	277.6	1.364	61273.	.150	156.84	24096.2	.001283
5	.8	295.6	1.395	61200.	.071	154.71	25902.9	.001379
6	1.3	318.0	1.432	61050.	.037	145.51	26806.1	.001427
7	2.2	340.1	1.466	60813.	.026	135.37	27126.1	.001444
8	4.3	370.5	1.503	60224.	.024	123.11	27264.4	.001451
9	7.7	398.1	1.524	59356.	.025	114.06	27270.2	.001452
10	10.8	413.5	1.525	58574.	.026	110.31	27279.5	.001452
11	17.4	441.6	1.519	57033.	.029	104.16	27246.6	.001450
12	23.9	463.8	1.505	55587.	.034	100.21	27173.7	.001446
13	30.5	481.0	1.484	54207.	.036	98.34	27140.7	.001445
14	37.0	499.0	1.465	52944.	.039	96.53	27096.7	.001442
15	43.5	517.4	1.448	51777.	.043	94.63	27045.1	.001440
16	48.0	529.5	1.436	51028.	.045	93.52	27005.4	.001437
17	52.4	538.9	1.422	50316.	.047	93.27	26976.1	.001436
18	56.6	546.6	1.408	49670.	.098	89.11	25748.4	.001371
19	58.6	520.9	1.362	49421.	.530	70.99	18442.5	.000982
20	59.3	440.6	1.247	49370.	-.026	162.40	28865.6	.001536

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.0	58.1	-.14	80.1	-.593E-01
2	54.1	57.4	1.42	248.2	.523E+00

RUN 808H, DATE 8/03/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 86.8 F, TOUT = 270.4 F, MASS FLOW RATE = 37.7 LB/HR, I = 89.8 AMPS, E = 5.820 VOLTS
PR,IN = .717, GR/RESQ = .176E-02, MACH(2) = .119, MACH(16) = .135, T,SURR = 106.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	210.3	1.225	55205.	-.129	299.94	29017.2	.001677
3	.3	251.3	1.299	55146.	.504	130.69	16857.8	.000974
4	.5	279.5	1.349	55082.	.161	144.86	21877.8	.001264
5	.8	297.6	1.380	55017.	.080	142.69	23544.5	.001361
6	1.3	319.5	1.416	54884.	.047	133.94	24327.8	.001406
7	2.2	336.5	1.440	54674.	.022	128.72	24957.9	.001442
8	4.3	371.9	1.485	54150.	.027	113.66	24913.7	.001440
9	7.7	398.6	1.505	53391.	.028	105.64	24941.9	.001441
10	10.8	413.6	1.505	52690.	.028	102.31	24950.5	.001442
11	17.4	443.5	1.503	51308.	.032	95.97	24907.8	.001439
12	23.9	466.6	1.491	50012.	.037	92.05	24829.4	.001435
13	30.5	484.3	1.470	48797.	.040	90.36	24792.4	.001433
14	37.0	502.8	1.452	47664.	.044	88.59	24742.3	.001430
15	43.5	519.3	1.433	46639.	.047	87.44	24699.4	.001427
16	48.0	535.1	1.427	45966.	.051	85.28	24630.6	.001423
17	52.4	541.3	1.409	45329.	.051	85.99	24626.5	.001423
18	56.6	550.3	1.396	44750.	.108	81.41	23388.1	.001352
19	58.6	526.9	1.354	44531.	.615	61.56	16013.9	.000925
20	59.3	442.9	1.236	44487.	-.042	154.77	26849.7	.001552

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	53.0	-.08	87.7	-.608E-01
2	54.1	52.4	1.40	256.7	.420E+00

RUN 809H, DATE 8/03/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 78.1 F, TOUT = 264.9 F, MASS FLOW RATE = 36.6 LB/HR, I = 89.7 AMPS, E = 5.795 VOLTS
PR,IN = .719, GR/RESQ = .187E-02, MACH(2) = .119, MACH(16) = .135, T,SURR = 106.3 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	204.6	1.239	54344.	-.132	293.41	29049.7	.001765
3	.3	245.4	1.314	54284.	.503	128.92	16828.1	.001022
4	.5	274.5	1.366	54219.	.161	142.78	21829.7	.001326
5	.8	293.5	1.399	54152.	.088	139.34	23317.1	.001417
6	1.3	315.8	1.436	54016.	.045	132.24	24330.8	.001478
7	2.2	335.1	1.465	53799.	.026	125.41	24815.6	.001508
8	4.3	366.0	1.502	53258.	.025	113.56	24881.4	.001512
9	7.7	392.7	1.521	52453.	.027	105.60	24894.5	.001513
10	10.8	409.5	1.523	51735.	.028	101.65	24694.8	.001513
11	17.4	440.8	1.521	50322.	.032	95.05	24853.5	.001510
12	23.9	465.8	1.510	49000.	.037	90.70	24773.0	.001505
13	30.5	486.2	1.491	47741.	.041	88.15	24728.1	.001502
14	37.0	506.4	1.474	46591.	.045	85.97	24672.5	.001499
15	43.5	524.3	1.455	45535.	.048	84.50	24621.7	.001496
16	48.0	538.7	1.445	44855.	.051	82.91	24569.3	.001493
17	52.4	551.3	1.435	44210.	.054	81.79	24524.3	.001490
18	56.6	562.1	1.424	43627.	.115	76.68	23207.1	.001410
19	58.6	531.9	1.372	43410.	.640	58.54	15744.3	.000957
20	59.3	444.8	1.248	43366.	-.046	149.63	26889.9	.001634

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	51.2	-.13	77.0	-.610E-01
2	54.1	50.6	1.43	250.9	.494E+00

RUN 810H, DATE 8/03/81, GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 78.1 F, TOUT = 259.1 F, MASS FLOW RATE = 37.6 LB/HR, I = 89.5 AMPS, E = 5.778 VOLTS
PR,IN = .719, GR/RESQ = .185E-02, MACH(2) = .119, MACH(16) = .135, T,SURR = 107.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	202.0	1.234	55892.	-.129	297.03	28799.1	.001701
3	.3	241.3	1.306	55832.	.479	133.65	17017.6	.001005
4	.5	269.5	1.357	55766.	.154	146.65	21851.2	.001291
5	.8	288.1	1.389	55700.	.088	142.30	23208.7	.001371
6	1.3	309.4	1.425	55564.	.043	135.51	24253.4	.001433
7	2.2	327.8	1.452	55349.	.025	128.62	24713.6	.001460
8	4.3	356.8	1.487	54809.	.024	116.94	24784.1	.001464
9	7.7	383.0	1.506	54004.	.026	108.63	24793.9	.001465
10	10.8	400.0	1.509	53287.	.027	104.37	24792.0	.001465
11	17.4	429.5	1.507	51875.	.031	97.99	24758.6	.001463
12	23.9	454.9	1.498	50551.	.036	93.23	24683.1	.001458
13	30.5	473.9	1.479	49280.	.039	90.89	24646.5	.001456
14	37.0	493.3	1.462	48125.	.042	88.77	24597.6	.001453
15	43.5	511.7	1.446	47052.	.046	87.01	24547.2	.001450
16	48.0	524.7	1.435	46368.	.048	85.72	24506.4	.001448
17	52.4	537.3	1.425	45717.	.051	84.53	24463.0	.001445
18	56.6	548.1	1.415	45129.	.109	79.39	23201.0	.001371
19	58.6	519.3	1.365	44908.	.602	61.64	16033.3	.000947
20	59.2	436.2	1.246	44862.	-.040	151.48	26598.6	.001571

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	52.5	-.11	77.0	-.606E-01
2	54.1	51.9	1.42	245.5	.497E+00

RUN 811H, DATE 8/03/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 76.3 F, TOUT = 295.5 F, MASS FLOW RATE = 12.6 LB/HR, I = 59.0 AMPS, E = 3.875 VOLTS
PR,IN = .719, GR/RESQ = .114E-02, MACH(2) = .096, MACH(16) = .111, T,SURR = 99.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	172.7	1.182	18813.	-.246	191.65	14434.5	.002547
3	.3	205.5	1.242	18790.	1.251	48.23	4843.9	.000855
4	.5	234.4	1.294	18768.	.320	67.58	8280.9	.001461
5	.8	255.7	1.332	18742.	.198	65.90	9140.8	.001613
6	1.3	285.1	1.382	18687.	.119	61.02	9807.1	.001731
7	2.2	312.4	1.424	18598.	.069	56.98	10287.7	.001815
8	4.3	350.7	1.472	18372.	.060	50.30	10403.8	.001836
9	7.7	383.0	1.495	18040.	.064	45.81	10388.8	.001833
10	10.8	402.3	1.496	17744.	.067	43.79	10370.5	.001830
11	17.4	435.0	1.487	17168.	.077	40.81	10296.5	.001817
12	23.9	461.8	1.470	16638.	.091	38.70	10184.2	.001797
13	30.5	484.5	1.447	16155.	.101	37.55	10109.0	.001784
14	37.0	507.1	1.427	15716.	.112	36.44	10021.5	.001768
15	43.5	526.8	1.405	15318.	.123	35.72	9939.4	.001754
16	48.0	539.9	1.391	15059.	.132	35.17	9869.9	.001742
17	52.4	544.8	1.367	14816.	.133	35.90	9862.4	.001740
18	56.6	552.5	1.351	14614.	.327	30.97	8428.4	.001487
19	58.6	500.0	1.274	14567.	5.234	8.34	1787.4	.000315
20	59.3	403.1	1.142	14555.	-.165	119.12	13249.8	.002338

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	21.9	.27	75.9	-.790E-01
2	54.1	21.7	1.36	281.8	.664E+00

RUN 812H, DATE 8/03/81, GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 72.8 F, TOUT = 297.5 F, MASS FLOW RATE = 12.7 LB/HR, I = 59.8 AMPS, E = 3.685 VOLTS
PR,IN = .720, GR/RESQ = .123E-02, MACH(2) = .095, MACH(16) = .111, T,SURR = 100.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNCLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	170.9	1.187	19074.	-.233	191.12	14575.1	.002566
3	.3	202.8	1.245	19051.	1.163	51.51	5178.4	.000912
4	.5	230.2	1.295	19027.	.284	72.02	8741.4	.001539
5	.8	250.6	1.331	19001.	.182	69.55	9509.4	.001674
6	1.3	278.7	1.379	18943.	.108	64.54	10165.8	.001790
7	2.2	305.0	1.419	18850.	.063	60.18	10615.4	.001869
8	4.3	342.4	1.465	18616.	.056	53.17	10722.2	.001888
9	7.7	373.7	1.486	18268.	.059	48.57	10712.1	.001886
10	10.8	393.1	1.486	17960.	.062	46.41	10693.4	.001883
11	17.4	426.3	1.477	17363.	.072	43.21	10620.5	.001870
12	23.9	452.7	1.458	16813.	.085	41.13	10517.0	.001852
13	30.4	474.0	1.433	16312.	.093	40.19	10450.7	.001840
14	37.0	494.8	1.409	15858.	.103	39.37	10375.2	.001827
15	43.5	514.1	1.386	15446.	.112	38.79	10300.6	.001814
16	48.0	528.1	1.373	15178.	.120	38.18	10239.0	.001803
17	52.4	540.6	1.358	14925.	.128	37.77	10181.8	.001793
18	56.6	551.5	1.346	14718.	.316	32.34	8730.2	.001537
19	58.6	498.6	1.269	14668.	4.326	10.17	2149.0	.000378
20	59.2	400.3	1.136	14655.	-.163	127.51	13573.2	.002390

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	22.2	.27	72.4	-.788E-01
2	54.1	22.0	1.35	283.4	.708E+00

RUN 813H, DATE 8/03/81, GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 72.3 F, TOUT = 291.5 F, MASS FLOW RATE = 12.7 LB/HR, I = 59.0 AMPS, E = 3.843 VOLTS
PR,IN = .720, GR/RESQ = .121E-02, MACH(2) = .094, MACH(16) = .110, T,SURR = 100.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	170.5	1.187	18997.	-.238	187.30	14275.0	.002527
3	.3	202.4	1.245	18974.	1.236	48.53	4877.2	.000864
4	.5	229.8	1.295	18951.	.293	69.68	8452.4	.001497
5	.8	250.2	1.331	18925.	.188	67.40	9210.7	.001631
6	1.3	278.3	1.379	18869.	.111	62.67	9868.4	.001747
7	2.2	304.6	1.420	18778.	.065	58.50	10317.3	.001827
8	4.3	341.9	1.466	18550.	.057	51.68	10423.6	.001846
9	7.7	373.3	1.488	18210.	.060	47.17	10413.0	.001844
10	10.8	392.7	1.489	17909.	.064	45.04	10393.6	.001840
11	17.4	425.5	1.481	17326.	.074	41.95	10321.9	.001828
12	23.9	451.8	1.463	16789.	.087	39.86	10218.3	.001809
13	30.4	472.7	1.438	16296.	.095	38.94	10154.4	.001798
14	37.0	494.0	1.416	15848.	.105	38.00	10076.6	.001784
15	43.5	513.3	1.394	15444.	.115	37.36	10002.8	.001771
16	48.0	527.7	1.381	15181.	.124	36.66	9936.9	.001759
17	52.4	539.3	1.367	14934.	.130	36.36	9887.8	.001751
18	56.6	550.7	1.355	14727.	.326	30.85	8431.7	.001493
19	58.6	497.3	1.277	14679.	4.883	8.82	1693.5	.000335
20	59.2	399.4	1.144	14666.	-.166	119.32	13263.2	.002348

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	22.2	.27	71.9	-.789E-01
2	54.1	22.0	1.36	277.9	.708E+00

RUN 814H, DATE 8/03/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 75.9 F, TOUT = 287.8 F, MASS FLOW RATE = 12.9 LB/HR, I = 58.5 AMPS, E = 3.826 VOLTS
PR,IN = .719, GR/RESQ = .119E-01, MACH(2) = .029, MACH(16) = .033, T,SURR = 101.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	174.0	1.184	19262.	-.249	185.90	14251.8	.002457
3	.3	207.2	1.244	19240.	1.377	44.15	4511.2	.000778
4	.5	236.1	1.296	19217.	.289	67.07	8338.3	.001437
5	.8	258.4	1.336	19192.	.260	60.45	8540.5	.001472
6	1.3	286.0	1.383	19139.	.106	60.25	9755.9	.001682
7	2.2	313.8	1.426	19050.	.071	55.38	10089.8	.001739
8	4.3	351.6	1.474	18828.	.059	49.12	10232.0	.001764
9	7.7	387.1	1.504	18499.	.066	44.12	10198.0	.001758
10	10.8	409.1	1.511	18206.	.070	41.71	10169.3	.001753
11	17.4	441.4	1.503	17637.	.080	38.89	10097.8	.001741
12	23.9	465.0	1.482	17111.	.094	37.21	9993.0	.001723
13	30.5	483.2	1.454	16629.	.101	36.61	9937.3	.001713
14	37.0	506.2	1.436	16187.	.113	35.35	9845.2	.001697
15	43.5	525.5	1.415	15790.	.124	34.62	9767.3	.001684
16	48.0	539.0	1.402	15531.	.134	33.96	9689.7	.001670
17	52.4	540.3	1.374	15288.	.133	35.09	9700.6	.001672
18	56.6	541.7	1.350	15080.	.312	31.22	8372.5	.001443
19	58.6	491.0	1.275	15031.	4.573	9.24	1964.5	.000339
20	59.3	393.5	1.141	15019.	-.168	118.81	13060.0	.002251

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	75.2	.28	76.3	-.786E-01
2	54.1	75.2	1.36	274.5	.191E+00

RUN 815H, DATE 8/03/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 72.8 F, TOUT = 282.9 F, MASS FLOW RATE = 13.0 LB/HR, I = 58.2 AMPS, E = 3.812 VOLTS
PR,IN = .720, GR/RESQ = .126E-01, MACH(2) = .028, MACH(16) = .033, T,SURR = 100.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	167.9	1.179	19440.	-.233	166.59	13794.2	.002380
3	.3	198.5	1.235	19418.	1.221	49.11	4776.1	.000824
4	.5	224.4	1.282	19395.	.255	72.39	8467.2	.001461
5	.8	244.3	1.317	19369.	.206	66.84	8625.3	.001523
6	1.3	270.6	1.362	19316.	.105	63.68	9647.8	.001665
7	2.2	295.6	1.401	19227.	.063	59.34	10052.6	.001735
8	4.3	331.4	1.445	19004.	.055	52.42	10153.7	.001752
9	7.6	363.6	1.471	18672.	.059	47.44	10134.5	.001749
10	10.8	384.4	1.477	18378.	.064	44.94	10109.6	.001745
11	17.4	417.3	1.472	17807.	.074	41.69	10040.2	.001733
12	23.9	442.3	1.455	17279.	.086	39.71	9945.8	.001716
13	30.4	460.9	1.429	16790.	.093	39.02	9892.8	.001707
14	37.0	480.9	1.408	16342.	.102	38.17	9822.7	.001695
15	43.5	498.9	1.386	15942.	.111	37.62	9757.5	.001684
16	48.0	512.4	1.374	15681.	.119	37.03	9696.8	.001674
17	52.4	523.2	1.359	15434.	.125	36.80	9655.3	.001666
18	56.6	532.7	1.347	15222.	.311	31.56	8287.8	.001430
19	58.6	481.5	1.270	15172.	4.267	9.94	2056.0	.000355
20	59.2	368.5	1.142	15159.	-.163	117.58	12852.4	.002218

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	75.6	.28	73.2	-.784E-01
2	54.1	75.6	1.35	269.7	.603E+00

RUN 816H, DATE 8/03/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 71.9 F, TOUT = 282.8 F, MASS FLOW RATE = 12.9 LB/HR, I = 58.2 AMPS, E = 3.815 VOLTS
PR,IN = .720, GR/RESQ = .129E-01, MACH(2) = .028, MACH(16) = .033, T,SURR = 100.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	167.4	1.180	19375.	-.236	186.73	13849.0	.002405
3	.3	198.5	1.237	19353.	1.256	48.07	4701.5	.000616
4	.5	224.8	1.285	19331.	.294	69.67	8211.2	.001426
5	.8	244.3	1.320	19305.	.184	67.80	8985.7	.001560
6	1.3	271.1	1.365	19251.	.107	63.26	9635.6	.001673
7	2.2	296.5	1.404	19162.	.064	58.89	10045.2	.001744
8	4.3	332.7	1.450	18939.	.055	52.00	10149.3	.001762
9	7.7	365.0	1.475	18605.	.060	47.09	10130.7	.001759
10	10.8	385.3	1.480	18311.	.064	44.71	10108.8	.001755
11	17.4	418.7	1.475	17738.	.074	41.42	10036.2	.001743
12	23.9	442.7	1.457	17210.	.086	39.60	9945.5	.001727
13	30.4	462.3	1.433	16720.	.094	38.77	9887.8	.001717
14	37.0	482.2	1.411	16272.	.103	37.93	9818.1	.001705
15	43.5	500.7	1.389	15872.	.112	37.32	9750.2	.001693
16	48.0	514.2	1.377	15611.	.120	36.74	9692.6	.001683
17	52.4	525.9	1.363	15364.	.126	36.37	9643.6	.001675
18	56.6	536.3	1.352	15153.	.318	30.97	8248.1	.001432
19	58.6	483.7	1.274	15103.	4.483	9.44	1975.3	.000343
20	59.2	390.3	1.145	15090.	-.163	115.45	12651.1	.002232

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	75.0	.28	72.3	-.765E-01
2	54.1	75.0	1.36	269.6	.604E+00

RUN 817H, DATE 8/03/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 81.2 F, TOUT = 272.4 F, MASS FLOW RATE = 25.5 LB/HR, I = 76.0 AMPS, E = 4.945 VOLTS
PR,IN = .718, GR/RESQ = .613E-02, MACH(2) = .054, MACH(16) = .061, T,SURR = 104.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	191.5	1.205	37616.	-.168	250.11	21723.3	.001885
3	.3	229.6	1.274	37575.	.758	88.54	10311.0	.000895
4	.5	257.8	1.324	37532.	.205	108.99	15071.1	.001308
5	.8	277.3	1.358	37486.	.122	105.82	16210.4	.001407
6	1.3	301.2	1.398	37391.	.066	99.89	17104.8	.001484
7	2.2	321.4	1.428	37239.	.033	95.05	17661.4	.001532
8	4.3	356.4	1.473	36856.	.034	84.14	17695.2	.001535
9	7.7	391.0	1.505	36297.	.039	75.75	17662.5	.001533
10	10.8	408.3	1.508	35792.	.040	72.81	17668.1	.001533
11	17.4	437.8	1.502	34799.	.045	68.42	17616.0	.001528
12	23.9	461.0	1.487	33872.	.052	65.60	17528.0	.001521
13	30.5	479.1	1.465	33003.	.056	64.31	17481.3	.001517
14	37.0	498.5	1.447	32198.	.061	62.87	17422.2	.001512
15	43.5	521.0	1.434	31471.	.068	60.79	17346.9	.001505
16	48.0	540.8	1.433	30997.	.076	58.35	17235.0	.001495
17	52.4	538.9	1.402	30551.	.074	60.65	17270.5	.001499
18	56.6	535.8	1.372	30151.	.152	58.90	16086.5	.001396
19	58.6	499.7	1.313	30013.	.977	40.12	9352.6	.000812
20	59.3	414.4	1.194	29982.	-.082	138.28	20010.3	.001736

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	78.4	.07	81.4	-.666E-01
2	54.1	78.3	1.39	258.6	.347E+00

RUN 818H, DATE 8/03/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 71.9 F, TOUT = 262.2 F, MASS FLOW RATE = 25.7 LB/HR, I = 76.0 AMPS, E = 4.919 VOLTS
PR,IN = .720, GR/RESQ = .663E-02, MACH(2) = .053, MACH(16) = .061, T,SURR = 103.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	184.1	1.212	38427.	-.162	247.68	21560.9	.001888
3	.3	219.1	1.277	38386.	.643	96.87	11026.6	.000966
4	.5	246.5	1.326	38341.	.191	113.16	15236.1	.001334
5	.8	265.5	1.360	38294.	.121	108.88	16221.6	.001420
6	1.3	288.6	1.399	38196.	.060	103.49	17184.0	.001505
7	2.2	309.0	1.430	38040.	.034	97.61	17630.1	.001544
8	4.3	339.4	1.467	37648.	.032	88.06	17711.4	.001551
9	7.7	365.7	1.485	37059.	.034	81.65	17715.7	.001551
10	10.8	382.7	1.488	36535.	.035	78.37	17706.9	.001550
11	17.4	412.9	1.484	35515.	.041	73.32	17658.3	.001546
12	23.9	436.5	1.471	34563.	.047	70.18	17585.5	.001540
13	30.4	455.9	1.452	33651.	.051	68.36	17540.4	.001536
14	37.0	475.4	1.434	32825.	.056	66.83	17486.3	.001531
15	43.5	494.0	1.416	32063.	.060	65.55	17430.9	.001526
16	48.0	507.5	1.406	31576.	.064	64.49	17382.9	.001522
17	52.4	519.1	1.394	31115.	.068	63.86	17342.9	.001519
18	56.6	530.0	1.384	30702.	.151	58.74	16093.5	.001409
19	58.6	495.7	1.327	30560.	.953	40.04	9463.6	.000829
20	59.2	410.4	1.205	30528.	-.078	133.64	19931.4	.001745

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	79.4	.05	72.0	-.662E-01
2	54.1	79.2	1.39	248.5	.576E+00

RUN 819H, DATE 8/03/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 71.4 F, TOUT = 263.2 F, MASS FLOW RATE = 25.3 LB/HR, I = 75.8 AMPS, E = 4.921 VOLTS
PR,IN = .720, GR/RESQ = .664E-02, MACH(2) = .053, MACH(16) = .061, T,SURR = 103.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	184.1	1.213	37927.	-.165	246.42	21521.5	.001912
3	.3	219.6	1.279	37886.	.661	94.77	10847.1	.000964
4	.5	247.4	1.329	37842.	.202	110.82	15026.5	.001335
5	.8	266.4	1.363	37795.	.118	107.87	16171.1	.001437
6	1.3	289.9	1.403	37698.	.062	101.96	17059.5	.001516
7	2.2	310.4	1.434	37542.	.035	96.40	17536.0	.001558
8	4.3	341.3	1.472	37152.	.032	86.87	17613.6	.001565
9	7.7	368.4	1.491	36566.	.034	80.31	17614.6	.001565
10	10.8	385.9	1.494	36044.	.036	76.99	17604.4	.001564
11	17.4	415.6	1.489	35030.	.041	72.21	17557.6	.001560
12	23.9	440.1	1.477	34083.	.048	68.90	17479.7	.001553
13	30.4	459.6	1.457	33178.	.052	67.14	17434.2	.001549
14	37.0	479.5	1.439	32358.	.057	65.53	17376.9	.001544
15	43.5	498.0	1.421	31602.	.062	64.30	17320.6	.001539
16	48.0	511.5	1.410	31120.	.066	63.27	17271.5	.001535
17	52.4	523.2	1.398	30662.	.069	62.65	17230.5	.001531
18	56.6	534.0	1.387	30253.	.155	57.54	15962.7	.001416
19	58.6	498.9	1.329	30113.	.983	38.83	9276.1	.000824
20	59.2	411.7	1.205	30082.	-.083	133.12	19929.6	.001771

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	78.4	.05	71.6	-.664E-01
2	54.1	78.2	1.39	249.4	.580E+00

RUN 820H, DATE 8/05/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 91.1 F, TOUT = 416.5 F, MASS FLOW RATE = 39.7 LB/HR, I = 122.8 AMPS, E = 8.135 VOLTS
PR,IN = .717, GR/RESQ = .749E-02, MACH(2) = .080, MACH(16) = .097, T,SURR = 151.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	319.2	1.416	57820.	-.131	300.73	54816.2	.002998
3	.3	385.7	1.535	57710.	.437	141.84	33313.9	.001822
4	.5	433.9	1.618	57587.	.140	154.57	42162.9	.002306
5	.8	466.4	1.673	57464.	.067	151.31	45137.2	.002469
6	1.3	512.4	1.747	57209.	.051	137.56	45982.9	.002515
7	2.2	553.3	1.805	56825.	.032	128.32	46965.8	.002569
8	4.3	609.4	1.864	55888.	.030	115.47	47256.3	.002585
9	7.7	656.4	1.884	54505.	.033	106.25	47280.0	.002586
10	10.9	688.5	1.880	53253.	.036	100.70	47250.8	.002584
11	17.4	755.4	1.875	50907.	.045	90.38	47037.5	.002573
12	23.9	788.5	1.823	48901.	.062	85.86	46419.4	.002539
13	30.5	816.5	1.768	47077.	.066	83.03	46224.7	.002528
14	37.1	865.7	1.748	45437.	.083	77.01	45751.3	.002502
15	43.7	892.8	1.703	43975.	.091	75.07	45485.1	.002488
16	48.1	910.4	1.674	43050.	.098	73.88	45251.4	.002475
17	52.5	905.6	1.620	42220.	.095	76.27	45356.4	.002481
18	56.7	908.6	1.582	41471.	.149	73.85	43238.2	.002365
19	58.8	868.8	1.521	41208.	.936	47.95	25591.1	.001400
20	59.4	725.4	1.353	41166.	-.045	141.42	51358.0	.002809

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	83.8	-.98	91.1	-.601E-01
2	54.2	83.3	1.60	392.9	.561E+00

RUN 821H, DATE 8/05/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 79.9 F, TOUT = 403.3 F, MASS FLOW RATE = 39.4 LB/HR, I = 122.0 AMPS, E = 8.102 VOLTS
PR,IN = .719, GR/RESQ = .803E-02, MACH(2) = .078, MACH(16) = .095, T,SURR = 150.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	314.2	1.436	58285.	-.136	296.22	54451.0	.003062
3	.3	382.6	1.560	58173.	.463	136.32	32301.1	.001816
4	.5	432.6	1.649	58048.	.157	148.75	41006.3	.002306
5	.8	464.7	1.704	57924.	.082	146.18	43918.1	.002469
6	1.3	504.8	1.769	57669.	.045	137.72	45610.4	.002565
7	2.2	542.5	1.822	57266.	.029	129.04	46442.6	.002611
8	4.3	600.7	1.886	56286.	.029	115.39	46634.5	.002622
9	7.7	651.6	1.912	54879.	.033	105.31	46638.9	.002622
10	10.9	683.3	1.907	53607.	.036	99.86	46611.1	.002621
11	17.4	737.1	1.880	51198.	.043	91.66	46473.1	.002613
12	23.9	784.3	1.848	49128.	.062	84.77	45796.1	.002575
13	30.5	817.9	1.800	47281.	.070	81.12	45549.5	.002561
14	37.1	853.7	1.760	45601.	.080	77.10	45222.7	.002543
15	43.7	878.6	1.712	44122.	.088	75.33	44986.4	.002529
16	48.1	899.3	1.685	43167.	.095	73.79	44751.3	.002516
17	52.5	915.2	1.656	42317.	.101	72.82	44579.6	.002507
18	56.7	933.0	1.634	41562.	.167	67.82	42102.1	.002367
19	58.8	880.2	1.558	41309.	1.040	43.20	23989.1	.001349
20	59.4	728.6	1.377	41271.	-.048	134.79	50897.7	.002862

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	83.9	****	80.0	-.600E-01
2	54.2	83.3	1.65	380.3	.674E+00

RUN 822H, DATE 8/05/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 79.5 F, TOUT = 397.8 F, MASS FLOW RATE = 39.9 LB/HR, I = 121.6 AMPS, E = 8.053 VOLTS
PR,IN = .719, GR/RESQ = .795E-02, MACH(2) = .078, MACH(16) = .095, T,SURR = 150.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	309.6	1.429	59005.	-.131	297.80	53744.8	.002989
3	.3	377.1	1.552	58894.	.454	138.65	32280.0	.001795
4	.5	424.4	1.636	58770.	.139	153.46	41345.7	.002300
5	.8	456.6	1.691	58646.	.085	147.88	43506.7	.002420
6	1.3	495.9	1.754	58392.	.045	139.67	45289.3	.002519
7	2.2	531.8	1.805	57992.	.028	131.30	46154.7	.002567
8	4.3	587.4	1.865	57014.	.028	117.74	46338.8	.002577
9	7.7	636.6	1.890	55612.	.032	107.65	46346.3	.002578
10	10.9	666.7	1.884	54345.	.034	102.32	46329.9	.002577
11	17.4	720.0	1.860	51934.	.041	93.85	46201.2	.002570
12	23.9	765.0	1.827	49857.	.058	87.20	45603.8	.002537
13	30.5	798.2	1.781	48005.	.066	83.55	45377.9	.002524
14	37.1	832.7	1.741	46310.	.075	79.59	45088.9	.002508
15	43.7	860.6	1.698	44824.	.083	77.28	44839.9	.002494
16	48.1	883.8	1.676	43864.	.091	75.29	44584.8	.002480
17	52.5	899.3	1.647	42999.	.096	74.42	44433.1	.002471
18	56.7	917.5	1.627	42239.	.161	69.26	41978.9	.002335
19	58.8	864.6	1.549	41983.	.978	45.40	24556.5	.001366
20	59.4	717.3	1.373	41943.	-.046	136.58	50386.3	.002803

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	84.7	****	79.5	-.598E-01
2	54.2	84.1	1.64	375.0	.688E+00

AD-A124 817 CONVECTIVE HEAT TRANSFER FOR SHIP PROPULSION(U) ARIZONA UNIV TUCSON ENGINEERING EXPERIMENT STATION J S PARK ET AL. 01 APR 82 1248-9 N00014-75-C-0694 2/2

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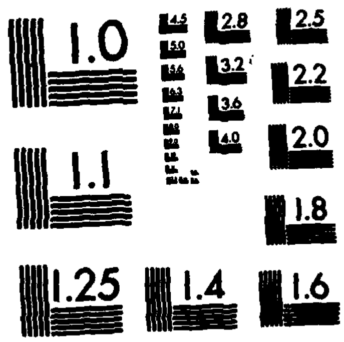

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

RUN 823H, DATE 8/06/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 92.4 F, TOUT = 238.2 F, MASS FLOW RATE = 66.2 LB/HR, I = 106.0 AMPS, E = 6.966 VOLTS
PR,IN = .716, GR/RESQ = .207E-02, MACH(2) = .131, MACH(16) = .145, T,SURR = 113.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	218.6	1.233	96489.	-.091	383.72	38780.0	.001268
3	.3	257.7	1.303	96401.	.301	205.73	27168.6	.000889
4	.5	284.7	1.350	96303.	.121	206.21	31595.7	.001033
5	.8	298.6	1.374	96211.	.047	206.46	33866.0	.001108
6	1.3	314.1	1.399	96024.	.023	197.35	34683.8	.001134
7	2.2	328.8	1.420	95729.	.017	187.34	34930.6	.001142
8	4.3	348.6	1.442	95011.	.015	175.55	35054.2	.001146
9	7.7	372.5	1.462	93942.	.017	163.01	35053.7	.001146
10	10.8	387.7	1.468	92949.	.017	156.83	35073.9	.001147
11	17.4	423.6	1.488	90973.	.021	142.57	35047.5	.001146
12	23.9	442.7	1.480	89106.	.023	137.77	35012.5	.001145
13	30.4	454.4	1.459	87290.	.024	136.79	35007.0	.001145
14	37.0	470.7	1.447	85610.	.026	133.99	34984.0	.001144
15	43.5	488.8	1.438	84022.	.028	130.49	34961.3	.001143
16	48.0	507.7	1.442	82987.	.032	125.18	34895.1	.001141
17	52.4	509.5	1.422	82033.	.031	127.65	34915.8	.001142
18	56.6	511.7	1.404	81155.	.063	125.97	33882.4	.001108
19	58.6	493.1	1.368	80790.	.316	110.25	27324.9	.000894
20	59.2	424.1	1.266	80718.	-.002	199.67	35833.3	.001172

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	85.0	-.20	90.8	-.535E-01
2	54.1	84.2	1.41	226.6	.336E+00

RUN 822H, DATE 8/05/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 79.5 F, TOUT = 397.8 F, MASS FLOW RATE = 39.9 LB/HR, I = 121.6 AMPS, E = 8.053 VOLTS
PR,IN = .719, GR/RESQ = .795E-02, MACH(2) = .078, MACH(16) = .095, T,SURR = 150.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	309.6	1.429	59005.	-.131	297.80	53744.8	.002989
3	.3	377.1	1.552	58894.	.454	138.65	32280.0	.001795
4	.5	424.4	1.636	58770.	.139	153.46	41345.7	.002300
5	.8	456.6	1.691	58646.	.085	147.88	43506.7	.002420
6	1.3	495.9	1.754	58392.	.045	139.67	45289.3	.002519
7	2.2	531.8	1.805	57992.	.028	131.30	46154.7	.002567
8	4.3	587.4	1.865	57014.	.028	117.74	46338.8	.002577
9	7.7	636.6	1.890	55612.	.032	107.65	46346.3	.002578
10	10.9	666.7	1.884	54345.	.034	102.32	46329.9	.002577
11	17.4	720.0	1.860	51934.	.041	93.85	46201.2	.002570
12	23.9	765.0	1.827	49857.	.058	87.20	45603.8	.002537
13	30.5	798.2	1.781	48005.	.066	83.55	45377.9	.002524
14	37.1	832.7	1.741	46310.	.075	79.59	45088.9	.002508
15	43.7	860.6	1.698	44824.	.083	77.28	44839.9	.002494
16	48.1	883.8	1.676	43864.	.091	75.29	44584.8	.002480
17	52.5	899.3	1.647	42999.	.096	74.42	44433.1	.002471
18	56.7	917.5	1.627	42239.	.161	69.26	41978.9	.002335
19	58.8	864.6	1.549	41983.	.978	45.40	24556.5	.001366
20	59.4	717.3	1.373	41943.	-.046	136.58	50386.3	.002803

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	84.7	****	79.5	-.598E-01
2	54.2	84.1	1.64	375.0	.688E+00

RUN 824H, DATE 8/06/81, GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 79.5 F, TOUT = 219.7 F, MASS FLOW RATE = 68.9 LB/HR, I = 106.0 AMPS, E = 6.966 VOLTS
PR,IN = .719, GR/RESQ = .226E-02, MACH(2) = .129, MACH(16) = .142, T,SURR = 112.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	208.4	1.243	102210.	-.081	379.11	38322.5	.001233
3	.3	245.1	1.311	102120.	.269	214.85	27827.7	.000895
4	.5	268.3	1.352	102018.	.095	219.10	32298.7	.001039
5	.8	282.8	1.378	101922.	.052	212.50	33661.3	.001083
6	1.3	297.2	1.401	101729.	.022	205.07	34671.5	.001116
7	2.2	310.0	1.420	101424.	.014	196.48	34986.7	.001126
8	4.3	332.5	1.447	100660.	.014	181.22	35032.1	.001127
9	7.7	354.1	1.465	99504.	.015	169.60	35055.0	.001128
10	10.8	368.4	1.470	98462.	.016	163.47	35067.2	.001128
11	17.4	394.2	1.475	96419.	.018	153.74	35063.9	.001128
12	23.8	416.8	1.474	94477.	.021	146.30	35032.5	.001127
13	30.4	434.5	1.464	92584.	.022	142.03	35022.6	.001127
14	37.0	454.0	1.458	90768.	.024	137.02	34999.8	.001126
15	43.5	471.7	1.450	89103.	.026	133.33	34977.0	.001125
16	48.0	483.4	1.444	88007.	.028	131.08	34959.8	.001125
17	52.4	495.6	1.439	86958.	.029	128.63	34934.3	.001124
18	56.6	505.0	1.432	86031.	.062	123.53	33888.9	.001090
19	58.6	485.5	1.394	85652.	.306	108.77	27513.3	.000885
20	59.2	418.8	1.293	85576.	.003	189.38	35657.8	.001147

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	88.5	-.24	78.0	-.528E-01
2	54.1	87.4	1.44	208.5	.452E+00

RUN 825H, DATE 8/06/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 77.7 F, TOUT = 222.4 F, MASS FLOW RATE = 66.7 LB/HR, I = 106.0 AMPS, E = 6.949 VOLTS
PR,IN = .719, GR/RESQ = .229E-02, MACH(2) = .129, MACH(16) = .143, T,SURR = 111.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	209.3	1.249	99257.	-.083	373.23	38394.0	.001279
3	.3	246.9	1.318	99167.	.277	209.64	27664.3	.000922
4	.5	270.6	1.361	99066.	.101	213.97	32127.7	.001071
5	.8	284.6	1.386	98969.	.047	210.46	33828.4	.001127
6	1.3	300.0	1.411	98775.	.024	201.16	34614.5	.001153
7	2.2	312.8	1.429	98469.	.014	193.29	34996.0	.001166
8	4.3	336.7	1.459	97701.	.015	177.53	35027.9	.001167
9	7.7	359.2	1.477	96541.	.016	165.87	35052.6	.001168
10	10.8	373.9	1.483	95490.	.017	159.78	35065.2	.001169
11	17.4	400.6	1.487	93443.	.019	150.09	35060.4	.001168
12	23.9	423.7	1.485	91501.	.021	142.83	35025.7	.001167
13	30.4	441.8	1.475	89610.	.023	138.59	35013.7	.001167
14	37.0	461.7	1.468	87799.	.025	133.66	34987.9	.001166
15	43.5	479.4	1.458	86146.	.027	130.25	34964.0	.001165
16	48.0	492.0	1.453	85055.	.029	127.77	34941.6	.001164
17	52.4	504.1	1.447	84013.	.031	125.51	34916.9	.001164
18	56.6	514.5	1.441	83101.	.065	120.10	33830.0	.001127
19	58.6	494.1	1.401	82726.	.320	105.06	27247.7	.000906
20	59.2	425.6	1.298	82652.	.003	185.11	35681.5	.001189

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	85.7	-.27	76.2	-.532E-01
2	54.1	84.2	1.44	211.0	.685E+00

RUN 826H, DATE 8/08/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 88.8 F, TOUT = 251.8 F, MASS FLOW RATE = 52.5 LB/HR, I = 100.0 AMPS, E = 6.550 VOLTS
PR,IN = .717, GR/RESQ = .191E-02, MACH(2) = .128, MACH(16) = .143, T,SURR = 108.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	215.7	1.235	76863.	-.103	345.84	34945.3	.001451
3	.3	257.2	1.310	76786.	.370	171.73	22957.4	.000953
4	.5	284.0	1.358	76701.	.119	182.15	28169.7	.001170
5	.8	301.7	1.388	76619.	.073	174.74	29410.3	.001221
6	1.3	319.5	1.417	76452.	.032	168.54	30633.6	.001272
7	2.2	334.7	1.438	76189.	.019	161.10	31040.6	.001289
8	4.3	359.5	1.467	75534.	.019	148.32	31101.9	.001291
9	7.7	383.0	1.484	74582.	.020	138.73	31116.5	.001292
10	10.8	398.1	1.487	73700.	.021	133.85	31124.4	.001292
11	17.4	427.2	1.490	71955.	.024	125.38	31105.7	.001291
12	23.9	456.6	1.494	70305.	.028	117.28	31034.8	.001289
13	30.5	479.3	1.486	68717.	.031	112.60	30997.8	.001287
14	37.0	498.7	1.473	67264.	.034	109.62	30956.9	.001285
15	43.5	513.9	1.456	65900.	.036	108.20	30922.9	.001284
16	48.0	524.2	1.444	65032.	.038	107.30	30892.5	.001283
17	52.4	531.8	1.429	64206.	.039	107.38	30873.9	.001282
18	56.6	538.6	1.416	63450.	.080	103.64	29722.5	.001234
19	58.6	520.1	1.380	63147.	.425	84.79	22499.0	.000934
20	59.2	438.9	1.263	63089.	-.024	177.75	32648.2	.001356

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	68.7	-.18	87.4	-.563E-01
2	54.1	68.0	1.42	239.2	.376E+00

RUN 827H, DATE 8/08/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 86.6 F, TOUT = 246.9 F, MASS FLOW RATE = 53.4 LB/HR, I = 100.0 AMPS, E = 6.515 VOLTS
PR,IN = .718, GR/RESQ = .205E-02, MACH(2) = .125, MACH(16) = .140, T,SURR = 106.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	212.6	1.235	78479.	-.101	348.67	34858.8	.001427
3	.3	251.8	1.305	78402.	.348	178.45	23320.6	.000955
4	.5	278.2	1.352	78317.	.124	185.25	28020.9	.001147
5	.8	294.4	1.380	78234.	.063	181.15	29667.8	.001215
6	1.3	312.2	1.409	78066.	.031	173.01	30638.8	.001255
7	2.2	327.3	1.431	77802.	.019	165.13	31041.3	.001271
8	4.3	352.7	1.461	77139.	.019	151.46	31099.9	.001274
9	7.7	377.0	1.480	76172.	.020	140.99	31112.2	.001274
10	10.8	392.2	1.484	75284.	.021	135.93	31121.8	.001274
11	17.4	420.4	1.486	73526.	.023	127.56	31102.9	.001274
12	23.9	444.9	1.482	71865.	.027	121.25	31046.1	.001271
13	30.4	463.4	1.469	70255.	.029	117.91	31022.1	.001270
14	37.0	483.8	1.459	68783.	.032	114.27	30981.3	.001269
15	43.5	501.4	1.446	67392.	.035	111.86	30946.4	.001267
16	48.0	514.8	1.440	66511.	.036	109.62	30891.9	.001265
17	52.4	513.9	1.413	65680.	.036	113.27	30947.1	.001267
18	56.6	534.6	1.420	64908.	.082	103.76	29675.2	.001215
19	58.6	511.1	1.377	64604.	.415	87.12	22637.3	.000927
20	59.2	434.9	1.266	64544.	-.014	176.12	32330.0	.001324

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	71.5	-.17	85.3	-.560E-01
2	54.1	70.6	1.42	234.4	.487E+00

RUN 828H, DATE 8/08/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 86.6 F, TOUT = 241.7 F, MASS FLOW RATE = 52.0 LB/HR, I = 97.2 AMPS, E = 6.497 VOLTS
PR,IN = .718, GR/RESQ = .193E-02, MACH(2) = .125, MACH(16) = .140, T,SURR = 108.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	214.0	1.237	76393.	-.106	327.81	33143.9	.001394
3	.3	253.2	1.308	76320.	.377	163.70	21581.4	.000908
4	.5	279.6	1.355	76240.	.136	171.96	26210.1	.001103
5	.8	295.4	1.382	76162.	.062	170.53	28066.5	.001181
6	1.3	313.6	1.412	76003.	.032	162.09	28902.3	.001216
7	2.2	329.7	1.436	75752.	.020	154.14	29282.7	.001232
8	4.3	355.5	1.467	75125.	.020	141.24	29349.8	.001235
9	7.7	379.4	1.486	74210.	.021	131.72	29363.4	.001235
10	10.8	394.6	1.490	73370.	.022	126.94	29370.2	.001236
11	17.4	423.2	1.494	71705.	.025	118.84	29346.9	.001235
12	23.9	448.2	1.493	70130.	.029	112.68	29285.5	.001232
13	30.4	467.6	1.482	68603.	.031	109.09	29256.8	.001231
14	37.0	488.9	1.474	67194.	.035	105.21	29210.4	.001229
15	43.5	507.3	1.463	65872.	.038	102.54	29168.9	.001227
16	48.0	520.4	1.457	65020.	.040	100.62	29134.9	.001226
17	52.4	533.8	1.451	64223.	.042	98.53	29090.9	.001224
18	56.6	544.2	1.444	63496.	.089	93.38	27872.9	.001173
19	58.6	519.3	1.399	63212.	.467	76.14	20654.4	.000869
20	59.2	442.3	1.286	63157.	-.015	157.03	30574.6	.001286

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	69.5	-.18	85.2	-.564E-01
2	54.1	68.7	1.45	229.8	.456E+00

RUN 829H, DATE 8/09/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 89.7 F, TOUT = 471.4 F, MASS FLOW RATE = 65.1 LB/HR, I = 168.6 AMPS, E = 11.310 VOLTS
PR,IN = .17, GR/RESQ = .733E-02, MACH(2) = .112, MACH(16) = .140, T,SURR = 201.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	420.0	1.606	95022.	-.094	380.15	99912.9	.003340
3	.3	511.9	1.769	94796.	.282	212.04	71099.5	.002377
4	.5	568.7	1.868	94543.	.083	222.24	84459.3	.002823
5	.8	609.0	1.935	94298.	.059	210.40	86656.8	.002897
6	1.3	657.2	2.010	93808.	.030	198.62	89354.4	.002987
7	2.2	706.2	2.077	93059.	.021	185.09	90486.3	.003025
8	4.3	794.9	2.179	91246.	.026	161.51	90634.8	.003030
9	7.7	856.0	2.200	88613.	.028	148.01	90803.3	.003035
10	10.9	896.1	2.189	86248.	.031	139.79	90785.3	.003035
11	17.4	973.8	2.161	81916.	.039	126.02	90530.7	.003026
12	24.0	1011.4	2.083	78290.	.059	118.62	89075.1	.002978
13	30.6	1040.8	2.002	75009.	.065	114.20	88762.1	.002967
14	37.2	1088.9	1.954	72110.	.076	107.85	88104.4	.002945
15	43.7	1119.6	1.892	69561.	.084	104.62	87660.3	.002930
16	48.2	1141.3	1.855	67962.	.090	102.23	87275.2	.002917
17	52.6	1144.7	1.801	66481.	.091	103.05	87250.5	.002917
18	56.8	1148.6	1.753	65143.	.120	101.45	84999.7	.002841
19	58.9	1109.0	1.691	64677.	.706	70.95	55673.7	.001861
20	59.5	943.3	1.507	64619.	-.003	162.66	94221.5	.003150

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	97.5	****	89.2	-.537E-01
2	54.4	96.3	1.78	443.2	.628E+00

RUN 830H, DATE 8/09/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 88.8 F, TOUT = 458.7 F, MASS FLOW RATE = 65.7 LB/HR, I = 166.8 AMPS, E = 11.250 VOLTS
PR,IN = .717, GR/RESQ = .721E-02, MACH(2) = .112, MACH(16) = .140, T,SURR = 196.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	414.3	1.598	96066.	-.103	381.58	98678.7	.003272
3	.3	502.2	1.755	95846.	.293	210.20	68917.7	.002285
4	.5	564.5	1.863	95595.	.108	214.29	80761.5	.002678
5	.8	603.0	1.928	95357.	.058	208.43	84876.9	.002815
6	1.3	648.9	1.999	94877.	.033	196.69	87212.8	.002892
7	2.2	690.2	2.054	94142.	.020	185.95	88527.0	.002936
8	4.3	763.2	2.131	92371.	.023	165.85	88742.1	.002943
9	7.7	830.0	2.166	89775.	.027	150.20	88815.7	.002945
10	10.9	875.6	2.167	87441.	.031	140.62	88774.5	.002944
11	17.4	941.9	2.128	83157.	.037	128.58	88617.6	.002939
12	23.9	993.9	2.075	79537.	.058	118.75	87165.2	.002890
13	30.6	1027.6	2.004	76255.	.065	113.47	86807.2	.002879
14	37.2	1061.8	1.941	73384.	.073	109.23	86375.1	.002864
15	43.7	1092.0	1.881	70814.	.080	106.12	85956.0	.002850
16	48.2	1114.5	1.646	69218.	.086	103.57	85605.5	.002839
17	52.6	1134.0	1.612	67730.	.092	101.61	85291.1	.002828
18	56.8	1151.9	1.781	66393.	.127	97.46	82669.3	.002741
19	58.9	1101.9	1.706	65911.	.734	68.46	53581.9	.001777
20	59.5	935.3	1.519	65850.	-.005	159.70	92370.4	.003063

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	98.4	****	88.3	-.535E-01
2	54.3	97.1	1.80	431.5	.689E+00

RUN 831H, DATE 8/09/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 88.8 F, TOUT = 470.8 F, MASS FLOW RATE = 64.5 LB/HR, I = 168.0 AMPS, E = 11.270 VOLTS
PR,IN = .717, GR/RESQ = .736E-02, MACH(2) = .111, MACH(16) = .140, T,SURR = 197.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	416.0	1.601	94282.	-.102	385.01	100090.0	.003382
3	.3	510.2	1.769	94056.	.306	207.16	69242.8	.002340
4	.5	572.4	1.878	93804.	.106	214.46	82182.2	.002777
5	.8	611.8	1.943	93563.	.057	208.13	86202.1	.002913
6	1.3	659.5	2.017	93076.	.034	195.78	88456.4	.002989
7	2.2	701.9	2.073	92332.	.021	185.04	89833.9	.003035
8	4.3	776.2	2.150	90539.	.023	165.02	90066.6	.003043
9	7.7	846.1	2.186	87911.	.028	148.94	90117.6	.003045
10	10.9	891.9	2.185	85555.	.032	139.50	90075.2	.003043
11	17.4	958.3	2.140	81254.	.038	127.70	89903.5	.003038
12	24.0	1009.8	2.083	77636.	.060	117.91	88354.2	.002985
13	30.6	1043.5	2.007	74373.	.067	112.77	87978.6	.002973
14	37.2	1078.6	1.943	71502.	.075	108.57	87511.4	.002957
15	43.7	1105.8	1.877	68968.	.082	105.92	87129.4	.002944
16	48.2	1130.9	1.844	67376.	.089	102.99	86711.9	.002930
17	52.6	1149.6	1.807	65896.	.094	101.34	86411.6	.002920
18	56.8	1170.1	1.778	64563.	.131	96.84	83682.1	.002827
19	58.9	1115.7	1.699	64116.	.756	67.73	53722.3	.001615
20	59.5	947.7	1.512	64061.	-.005	160.21	93748.4	.003168

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	96.8	****	88.3	-.538E-01
2	54.4	95.4	1.79	442.8	.727E+00

RUN 832H, DATE 8/09/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 88.8 F, TOUT = 514.0 F, MASS FLOW RATE = 51.7 LB/HR, I = 159.6 AMPS, E = 10.740 VOLTS
PR,IN = .717, GR/RESQ = .772E-02, MACH(2) = .103, MACH(16) = .131, T,SURR = 210.3 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	425.2	1.617	75508.	-.128	347.91	93003.6	.003923
3	.3	519.0	1.784	75311.	.362	175.77	59983.0	.002530
4	.5	592.3	1.912	75088.	.136	181.25	72315.3	.003050
5	.8	639.1	1.991	74872.	.076	175.63	76562.5	.003229
6	1.3	696.5	2.080	74435.	.042	164.95	79422.9	.003350
7	2.2	751.5	2.155	73770.	.028	153.64	80753.0	.003406
8	4.3	839.0	2.246	72163.	.031	135.57	81052.8	.003419
9	7.7	916.7	2.281	69826.	.037	121.60	80994.3	.003416
10	10.9	961.2	2.264	67749.	.041	114.29	80900.8	.003412
11	17.4	1022.3	2.189	64067.	.049	105.65	80648.6	.003402
12	24.0	1081.2	2.125	60954.	.081	95.73	78544.0	.003313
13	30.6	1102.8	2.021	58243.	.087	93.40	78275.7	.003301
14	37.2	1143.6	1.953	55840.	.099	89.33	77590.6	.003273
15	43.8	1163.5	1.871	53761.	.105	87.94	77262.7	.003259
16	48.3	1180.9	1.825	52431.	.112	86.77	76917.6	.003244
17	52.7	1187.7	1.771	51228.	.114	87.21	76799.0	.003239
18	56.9	1192.1	1.722	50184.	.148	85.43	74516.0	.003143
19	58.9	1146.9	1.656	49821.	.968	53.61	43342.3	.001828
20	59.6	966.8	1.465	49777.	-.021	149.38	86123.6	.003632

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	84.3	****	88.6	-.565E-01
2	54.4	83.2	1.75	483.4	.815E+00

RUN 833H, DATE 8/09/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 89.3 F, TOUT = 509.6 F, MASS FLOW RATE = 51.3 LB/HR, I = 158.4 AMPS, E = 10.633 VOLTS
PR,IN = .717, GR/RESQ = .681E-02, MACH(2) = .109, MACH(16) = .139, T,SURR = 208.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	430.3	1.625	74845.	-.124	336.82	91327.0	.003881
3	.3	527.7	1.799	74650.	.389	166.56	57957.6	.002463
4	.5	596.3	1.918	74434.	.136	177.18	71240.8	.003028
5	.8	638.7	1.989	74223.	.065	174.97	76197.4	.003238
6	1.3	693.6	2.074	73792.	.041	163.32	78233.7	.003325
7	2.2	745.5	2.143	73141.	.028	152.84	79575.2	.003382
8	4.3	831.6	2.233	71560.	.031	134.88	79810.8	.003392
9	7.7	910.4	2.270	69259.	.037	120.72	79734.1	.003389
10	10.9	954.0	2.254	67215.	.041	113.59	79658.1	.003385
11	17.4	1020.6	2.189	63582.	.050	104.20	79361.2	.003373
12	24.0	1073.9	2.119	60517.	.081	95.15	77353.1	.003287
13	30.6	1108.1	2.032	57836.	.090	91.11	76868.8	.003267
14	37.2	1143.2	1.958	55466.	.101	87.65	76288.7	.003242
15	43.8	1170.2	1.884	53415.	.110	85.51	75819.7	.003222
16	48.3	1192.3	1.843	52103.	.118	83.68	75389.2	.003204
17	52.7	1213.2	1.805	50907.	.126	82.15	74969.0	.003186
18	56.9	1233.3	1.772	49881.	.172	77.90	72109.8	.003065
19	58.9	1166.7	1.684	49546.	1.132	47.21	39457.5	.001677
20	59.6	983.7	1.489	49505.	-.041	144.12	86651.9	.003683

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	78.8	****	88.9	-.566E-01
2	54.4	77.8	1.79	480.0	.687E+00

RUN 834H, DATE 8/09/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 89.3 F, TOUT = 506.2 F, MASS FLOW RATE = 52.0 LB/HR, I = 158.8 AMPS, E = 10.656 VOLTS
PR,IN = .717, GR/RESQ = .677E-02, MACH(2) = .109, MACH(16) = .139, T,SURR = 206.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	C+
2	.1	422.1	1.611	75974.	-.128	347.97	92098.6	.003856
3	.3	516.0	1.778	75779.	.367	174.59	59131.2	.002476
4	.5	588.4	1.904	75559.	.143	179.72	71128.8	.002978
5	.8	632.1	1.977	75347.	.071	176.97	76139.3	.003188
6	1.3	686.2	2.061	74916.	.040	166.33	78689.8	.003295
7	2.2	738.1	2.131	74259.	.027	155.37	79963.4	.003348
8	4.3	822.9	2.219	72670.	.030	137.27	80226.6	.003359
9	7.7	900.0	2.255	70356.	.036	123.04	80170.8	.003357
10	10.9	944.0	2.241	68297.	.040	115.69	80095.6	.003353
11	17.4	1011.1	2.179	64628.	.049	106.03	79808.9	.003341
12	24.0	1062.7	2.108	61536.	.078	97.16	77891.3	.003261
13	30.6	1096.8	2.023	58821.	.087	93.04	77420.6	.003241
14	37.2	1131.5	1.949	56418.	.098	89.80	76867.5	.003218
15	43.8	1160.1	1.879	54341.	.107	87.19	76376.7	.003198
16	48.3	1181.9	1.838	53014.	.114	85.37	75965.1	.003181
17	52.7	1201.4	1.799	51797.	.121	84.03	75586.0	.003165
18	56.9	1222.0	1.767	50756.	.166	79.70	72766.4	.003047
19	58.9	1160.2	1.683	50412.	1.087	48.80	40489.7	.001695
20	59.6	974.3	1.485	50374.	-.023	144.36	85465.7	.003578

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	79.8	****	88.9	-.564E-01
2	54.4	78.7	1.78	476.7	.765E+00

RUN 835H, DATE 8/10/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 85.7 F, TOUT = 164.4 F, MASS FLOW RATE = 52.6 LB/HR, I = 70.4 AMPS, E = 4.618 VOLTS
PR,IN = .718, GR/RESQ = .882E-03, MACH(2) = .134, MACH(16) = .141, T,SURR = 93.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	151.0	1.124	77434.	-.095	329.91	17089.2	.000712
3	.3	173.5	1.165	77395.	.376	162.14	11256.6	.000469
4	.5	185.6	1.186	77353.	.113	176.80	13931.6	.000580
5	.8	193.4	1.200	77313.	.059	172.79	14650.4	.000610
6	1.3	201.7	1.214	77230.	.028	166.22	15107.3	.000629
7	2.2	209.2	1.225	77099.	.018	158.89	15258.2	.000635
8	4.3	222.6	1.242	76769.	.018	145.65	15269.4	.000636
9	7.6	237.1	1.258	76265.	.020	134.38	15257.9	.000635
10	10.8	244.8	1.262	75796.	.020	130.46	15263.6	.000636
11	17.4	259.8	1.269	74889.	.023	123.44	15245.8	.000635
12	23.8	269.3	1.265	74014.	.025	121.15	15225.9	.000634
13	30.4	280.1	1.264	73145.	,027	117.99	15211.0	.000634
14	37.0	286.5	1.256	72301.	.027	118.51	15207.7	.000633
15	43.5	295.1	1.252	71484.	.029	117.15	15195.0	.000633
16	47.9	299.6	1.246	70935.	.030	117.33	15188.2	.000633
17	52.3	301.8	1.238	70406.	.030	119.36	15187.7	.000633
18	56.5	303.7	1.230	69915.	.059	118.36	14776.2	.000615
19	58.5	301.6	1.221	69705.	.323	97.54	11822.2	.000492
20	59.2	264.1	1.160	69660.	-.004	179.66	15656.8	.000652

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	65.5	.40	83.9	-.562E-01
2	54.0	65.0	1.23	158.0	.246E+00

RUN 836H, DATE 8/10/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 84.8 F, TOUT = 162.9 F, MASS FLOW RATE = 53.1 LB/HR, I = 70.4 AMPS, E = 4.600 VOLTS
PR,IN = .718, GR/RESQ = .921E-03, MACH(2) = .132, MACH(16) = .139, T,SURR = 92.7 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	148.8	1.121	78173.	-.096	337.38	17103.3	.000708
3	.3	168.6	1.157	78136.	.346	173.77	11500.1	.000476
4	.5	181.2	1.180	78094.	.120	182.23	13840.4	.000573
5	.8	189.1	1.194	78053.	.059	178.78	14647.5	.000606
6	1.3	197.4	1.207	77970.	.027	171.66	15109.3	.000625
7	2.2	204.8	1.218	77838.	.017	163.84	15262.7	.000631
8	4.3	218.5	1.237	77507.	.018	149.39	15266.8	.000632
9	7.6	231.7	1.251	77003.	.019	139.03	15265.5	.000632
10	10.8	239.8	1.255	76530.	.020	134.35	15264.4	.000631
11	17.4	252.5	1.258	75619.	.022	128.98	15253.6	.000631
12	23.8	263.4	1.258	74741.	.024	125.30	15228.2	.000630
13	30.4	272.0	1.253	73870.	.025	123.89	15220.8	.000630
14	37.0	281.0	1.249	73022.	.027	122.11	15210.7	.000629
15	43.5	290.1	1.246	72201.	.028	120.32	15200.5	.000629
16	47.9	296.4	1.244	71650.	.029	119.00	15193.0	.000629
17	52.3	302.8	1.242	71117.	.030	117.62	15184.9	.000628
18	56.5	308.7	1.241	70623.	.064	112.77	14709.3	.000609
19	58.5	297.5	1.218	70416.	.304	101.00	11986.9	.000496
20	59.2	261.8	1.159	70369.	-.000	180.63	15594.5	.000645

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	67.3	.40	83.1	-.561E-01
2	54.0	66.6	1.24	156.6	.372E+00

RUN 837H, DATE 8/10/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 86.6 F, TOUT = 165.5 F, MASS FLOW RATE = 52.5 LB/HR, I = 70.4 AMPS, E = 4.593 VOLTS
PR,IN = .718, GR/RESQ = .920E-03, MACH(2) = .132, MACH(16) = .139, T,SURR = 92.3 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	150.1	1.120	77152.	-.098	339.73	17149.5	.000715
3	.3	170.4	1.157	77114.	.358	171.79	11402.3	.000475
4	.5	183.4	1.180	77073.	.134	178.69	13669.8	.000570
5	.8	190.8	1.193	77032.	.049	179.96	14781.2	.000616
6	1.3	199.6	1.207	76949.	.029	170.21	15079.5	.000628
7	2.2	207.0	1.218	76819.	.018	162.80	15260.4	.000636
8	4.3	220.8	1.237	76489.	.018	148.43	15264.7	.000636
9	7.6	234.4	1.251	75987.	.020	137.72	15259.9	.000636
10	10.8	242.1	1.255	75524.	.020	133.60	15262.3	.000636
11	17.4	255.2	1.256	74620.	.022	127.93	15249.6	.000636
12	23.8	266.1	1.258	73747.	.025	124.34	15224.5	.000635
13	30.4	274.7	1.253	72881.	.026	123.02	15217.0	.000634
14	37.0	283.8	1.249	72038.	.027	121.32	15206.7	.000634
15	43.5	292.8	1.246	71222.	.028	119.59	15195.9	.000633
16	47.9	298.7	1.243	70674.	.029	118.71	15190.4	.000633
17	52.3	305.5	1.242	70145.	.031	116.99	15179.3	.000633
18	56.5	311.0	1.239	69654.	.065	112.49	14698.9	.000613
19	58.5	299.8	1.216	69450.	.313	100.21	11907.8	.000496
20	59.2	263.2	1.156	69404.	-.002	182.69	15625.5	.000651

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	66.7	.41	84.9	-.563E-01
2	54.0	66.0	1.24	159.2	.372E+00

RUN 838H, DATE 8/10/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 82.1 F, TOUT = 162.9 F, MASS FLOW RATE = 24.3 LB/HR, I = 48.6 AMPS, E = 3.232 VOLTS
PR,IN = .718, GR/RESQ = .259E-02, MACH(2) = .054, MACH(16) = .056, T,SURR = 88.3 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	128.8	1.087	35870.	-.177	242.52	8943.4	.000812
3	.3	145.7	1.118	35854.	.797	81.96	4098.7	.000372
4	.5	158.9	1.141	35837.	.283	95.44	5745.8	.000521
5	.8	166.8	1.155	35819.	.089	102.32	6777.4	.000615
6	1.3	177.9	1.174	35779.	.060	93.56	6969.7	.000633
7	2.2	188.8	1.192	35717.	.042	86.13	7094.7	.000644
8	4.3	203.7	1.212	35561.	.036	77.44	7142.5	.000648
9	7.6	217.4	1.227	35323.	.038	71.23	7134.5	.000647
10	10.8	225.6	1.232	35101.	.039	68.66	7130.9	.000647
11	17.4	239.7	1.237	34670.	.044	64.99	7108.9	.000645
12	23.8	250.5	1.236	34258.	.049	62.93	7077.1	.000642
13	30.4	258.3	1.230	33851.	.051	62.64	7067.3	.000641
14	37.0	267.3	1.226	33455.	.054	61.68	7051.6	.000640
15	43.5	276.4	1.223	33072.	.057	60.69	7035.5	.000638
16	47.9	281.8	1.220	32815.	.060	60.36	7021.9	.000637
17	52.3	283.2	1.210	32569.	.060	62.04	7024.0	.000637
18	56.5	284.1	1.200	32343.	.125	60.15	6614.8	.000600
19	58.5	272.0	1.177	32261.	.865	40.83	3988.0	.000362
20	59.2	231.2	1.110	32241.	-.092	134.60	8164.3	.000741

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	75.5	.60	82.0	-.674E-01
2	54.0	75.4	1.21	156.9	.844E-01

RUN 839H, DATE 8/10/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 82.6 F, TOUT = 162.1 F, MASS FLOW RATE = 24.3 LB/HR, I = 48.2 AMPS, E = 3.232 VOLTS
PR,IN = .718, GR/RESQ = .253E-02, MACH(2) = .053, MACH(16) = .056, T,SURR = 88.0 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	129.3	1.087	35773.	-.174	237.45	8766.0	.000797
3	.3	145.3	1.116	35757.	.729	84.94	4191.2	.000381
4	.5	158.0	1.139	35740.	.248	98.20	5812.7	.000528
5	.8	166.4	1.154	35722.	.122	98.62	6470.0	.000588
6	1.3	176.6	1.171	35684.	.062	93.45	6838.0	.000621
7	2.2	185.8	1.185	35623.	.038	87.89	7003.7	.000636
8	4.3	199.8	1.204	35470.	.035	79.08	7027.5	.000639
9	7.6	212.5	1.217	35236.	.037	73.13	7022.1	.000638
10	10.8	220.6	1.222	35017.	.039	70.38	7015.6	.000637
11	17.4	233.3	1.225	34595.	.042	67.21	6997.8	.000636
12	23.8	244.7	1.226	34189.	.048	64.73	6964.4	.000633
13	30.4	253.3	1.222	33788.	.051	63.95	6952.7	.000632
14	37.0	262.8	1.219	33398.	.054	62.68	6936.4	.000630
15	43.5	271.9	1.216	33021.	.057	61.64	6921.5	.000629
16	47.9	278.2	1.215	32768.	.059	60.87	6910.7	.000628
17	52.3	284.6	1.213	32524.	.061	60.07	6899.2	.000627
18	56.5	290.5	1.212	32302.	.138	55.41	6436.1	.000585
19	58.5	273.9	1.181	32223.	.881	38.95	3889.3	.000353
20	59.2	233.9	1.115	32204.	-.086	125.58	8001.7	.000727

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	76.4	.59	82.5	-.674E-01
2	54.0	76.2	1.21	156.3	.414E+00

RUN 840H, DATE 8/10/81 , GAS AIR(PULSED) , MOLECULAR WT. = 28.97
TIN = 78.6 F, TOUT = 149.4 F, MASS FLOW RATE = 26.5 LB/HR, I = 48.0 AMPS, E = 3.231 VOLTS
PR,IN = .719, GR/RESQ = .468E-03, MACH(2) = .122, MACH(16) = .129, T,SURR = 87.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	124.8	1.089	39362.	-.163	235.78	8572.8	.000718
3	.3	139.9	1.117	39346.	.694	88.31	4239.8	.000355
4	.5	151.3	1.138	39328.	.153	109.95	6237.6	.000523
5	.8	160.2	1.154	39309.	.160	97.67	6201.4	.000520
6	1.3	169.0	1.169	39272.	.055	97.49	6822.1	.000572
7	2.2	177.0	1.181	39211.	.033	92.31	6972.1	.000584
8	4.3	190.2	1.200	39056.	.032	83.03	6983.2	.000585
9	7.6	202.4	1.213	38821.	.035	76.59	6975.7	.000585
10	10.8	209.9	1.218	38601.	.036	73.83	6971.1	.000584
11	17.3	221.5	1.221	38159.	.039	70.65	6955.1	.000583
12	23.8	232.0	1.222	37750.	.045	68.14	6923.4	.000580
13	30.4	240.6	1.219	37344.	.047	66.94	6910.0	.000579
14	37.0	247.4	1.214	36949.	.049	66.77	6900.7	.000578
15	43.5	255.1	1.210	36566.	.052	66.06	6889.1	.000577
16	47.9	261.9	1.211	36309.	.055	64.68	6871.6	.000576
17	52.3	264.6	1.204	36061.	.055	65.61	6872.7	.000576
18	56.5	267.8	1.200	35833.	.116	62.55	6499.6	.000545
19	58.5	257.5	1.179	35748.	.750	44.27	4140.1	.000347
20	59.1	220.4	1.117	35728.	-.080	129.75	7851.9	.000658

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	36.0	.60	77.1	-.659E-01
2	54.0	35.7	1.20	144.0	.295E+00

RUN 841H, DATE 8/10/81 , GAS AIR(STEADY) , MOLECULAR WT. = 28.97
TIN = 78.1 F, TOUT = 148.7 F, MASS FLOW RATE = 26.6 LB/HR, I = 48.0 AMPS, E = 3.230 VOLTS
PR,IN = .719, GR/RESQ = .488E-03, MACH(2) = .123, MACH(16) = .130, T,SURR = 87.5 F

TC	X/D	TW (F)	TW/TB	BULK REYNOLDS	HL/QGAS	BULK NUSSELT	QGAS BTU/HRFT2	Q+
2	.1	125.3	1.091	39507.	-.163	231.50	8573.0	.000717
3	.3	140.4	1.119	39491.	.695	87.08	4238.7	.000354
4	.5	151.8	1.139	39473.	.222	102.45	5882.3	.000492
5	.8	159.3	1.153	39455.	.105	103.21	6511.6	.000545
6	1.3	168.6	1.169	39417.	.059	97.18	6795.7	.000568
7	2.2	176.6	1.181	39356.	.034	92.29	6966.6	.000583
8	4.3	188.8	1.198	39201.	.032	83.82	6987.4	.000584
9	7.6	200.7	1.211	38966.	.034	77.54	6978.3	.000584
10	10.8	207.7	1.215	38745.	.035	75.01	6975.1	.000583
11	17.3	219.3	1.218	38302.	.038	71.78	6958.4	.000582
12	23.8	229.2	1.218	37892.	.044	69.47	6927.6	.000579
13	30.4	237.4	1.215	37485.	.046	68.51	6916.2	.000578
14	37.0	246.0	1.213	37089.	.049	67.28	6902.1	.000577
15	43.5	254.2	1.210	36706.	.052	66.30	6889.4	.000576
16	47.9	260.1	1.209	36448.	.053	65.47	6880.2	.000575
17	52.3	266.4	1.209	36199.	.056	64.33	6867.4	.000574
18	56.5	271.4	1.207	35971.	.122	60.12	6465.2	.000541
19	58.5	257.1	1.179	35887.	.723	44.93	4204.8	.000352
20	59.1	220.8	1.119	35867.	-.075	127.13	7809.5	.000653

PT	X/D	STATIC PRESS.(PSIA)	TW/TB	TB (F)	PRESS DEFECT
1	-5.9	35.9	.61	76.7	-.658E-01
2	54.0	35.5	1.21	143.4	.452E+00

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